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THESIS

**THE USE OF SIMULATION
TO EVALUATE INVENTORY MODELS
FOR MANAGEMENT
OF HAZARDOUS MATERIAL**

by

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December, 1995

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A problem for the Navy Supply System is identifying the proper inventory model for managing a Hazardous Material Minimization Center. This thesis analyzes three recently proposed inventory models: two continuous review economic order quantity (EOQ) inventory models and a periodic review inventory model. Based on this analysis, the authors develop both a continuous review EOQ model and a periodic review model for evaluation. These models differ from the previous ones in that they comprise all of the relevant hazardous material inventory costs including extension of shelf-life. The two new models are then evaluated through the use of simulation. A base set of data was first used in simulating both models. This was then followed by four additional simulated scenarios providing sensitivity analyses of demand-related changes to each model. The thesis' analysis focuses on total variable costs as the primary tool for evaluating the models. The results in all cases were very close, suggesting that it can be left to the inventory managers as to whether to use a continuous review or periodic review model. Additional testing with actual demand data is strongly recommended before any implementation of either model.

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THE USE OF SIMULATION TO EVALUATE INVENTORY MODELS FOR MANAGEMENT OF HAZARDOUS MATERIAL

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ABSTRACT

A problem for the Navy Supply System is identifying the proper inventory model for managing a Hazardous Material Minimization Center. This thesis analyzes three recently proposed inventory models: two continuous review economic order quantity (EOQ) inventory models and a periodic review inventory model. Based on this analysis, the authors develop both a continuous review EOQ model and a periodic review model for evaluation. These models differ from the previous ones in that they comprise all of the relevant hazardous material inventory costs including extension of shelf-life. The two new models are then evaluated through the use of simulation. A base set of data was first used in simulating both models. This was then followed by four additional simulated scenarios providing sensitivity analyses of demand-related changes to each model. The thesis' analysis focuses on total variable costs as the primary tool for evaluating the models. The results in all cases were very close, suggesting that it can be left to the inventory managers as to whether to use a continuous review or periodic review model. Additional testing with actual demand data is strongly recommended before any implementation of either model.

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I. INTRODUCTION

A. THE PROBLEM

Hazardous material (HAZMAT) management is a critical concern for both public and private sector organizations. The increasing cost of disposal and misuse elevates the importance of developing techniques that will assist in minimizing the use of hazardous material and all of the associated costs.

HAZMAT management incorporates additional holding, disposal, extension, shortage, and transportation costs. Piburn and Smith (1994) examined some of these costs in their thesis. They also developed theoretical models, both a continuous review and a periodic review model, but were unable to test them because of insufficient recorded demand history.

Because extension of expired shelf-life material can significantly lower the costs associated with hazardous material, Murray (1995) examined the current shelf-life extension program in his thesis. He developed a hazardous material continuous review inventory model as part of his analysis which allowed for determining the economic benefits of shelf-life extensions.

Testing of these proposed inventory models was needed to determine the most appropriate model to be used in the replenishment of "A" condition material. However, there is currently a lack of sufficient useable data on the demand of HAZMAT at the Navy's Hazardous Material Minimization Centers (HAZMINCEN). The determination of an appropriate inventory model requires at least two years of demand history to use in the testing of the models. Since such data does not exist, the use of simulation modeling is the next best approach.

B. THESIS OBJECTIVE

A simulation model is developed in this thesis to generate demand for hazardous material and to compare the cost effectiveness of proposed inventory models for managing HAZMAT. In the process of developing that model it became clear that the previously developed continuous review and periodic review models were missing important cost components. Thus, two models are developed, one continuous review and the other

periodic review, and they are evaluated using the simulation model.

C. RESEARCH QUESTIONS

As part of the objective, this thesis seeks answers to the following research questions:

1. What are the current operational procedures being used for HAZMAT management?

2. Can these operational procedures be replicated in a computer simulation model, including shelf-life issues and the receipt of CA material? CA material is reusable HAZMAT returned by a customer that can be reissued to other customers, usually at no cost to the customer.

3. How can previously proposed inventory models be modified to account for shelf-life extension issues and the receipt of CA material, such that there is both a continuous review and a periodic review inventory model to consider?

4. How do the new proposed inventory models perform with respect to total annual variable costs for managing hazardous material inventories?

D. SCOPE OF THE STUDY

The simulation model developed in this thesis provides simulated random data from assumed probability distributions for the following items:

1. Demand for hazardous material which includes both requisition frequency and quantity per requisition.
2. The receipt of cost avoidance (CA) material.
3. The length of the extension time of expired shelf-life material derived from a simulation model.

A comparative cost analysis, based on the average annual total variable inventory management costs, was then conducted to determine the expected financial impact of each inventory model proposed in this thesis.

E. METHODOLOGY

A simulation model which attempts to replicate HAZMINCEN operations and the replenishment procedures currently in place was developed using SIMAN (SIMulation ANalysis) software. Data was generated for use in evaluating the proposed inventory

models. Replenishment decisions resulting from the inventory models being tested were also incorporated into the simulation models. The simulation output data provided the average annual total variable costs resulting from using the proposed inventory models under a prescribed set of conditions which made up the basic scenario. Each inventory model was then tested under four other scenarios to determine the sensitivity of each inventory model to changes in certain demand and extension parameters.

F. THESIS OVERVIEW

This thesis is divided into seven chapters. Chapter I has presented the problem, stated the objective of the thesis and the associated research questions, described the scope of the research effort, and previewed the research methodology. Chapter II discusses the issues associated with the inventory management practices of a HAZMINCEN and concerns in the management of both hazardous waste disposal and shelf-life material. Chapter III reviews previously proposed inventory management models for use in the management of HAZMAT. Chapter IV develops and proposes two more comprehensive inventory management models for use in the management of HAZMAT. Chapter V discusses simulation modeling procedures in general and as they specifically relate to the simulation model developed in this research. It also discusses the specific conditions and requirements for running the simulation model developed as part of this research for both of the models developed in Chapter IV. Chapter VI presents a comparative analysis of the models' performances using the simulated total annual variable costs generated for each inventory model. Chapter VII presents a summary of the thesis efforts, conclusions from the research, and recommendations for further study.

A list of acronyms and abbreviations can be found in Appendix A. Appendix B lists the simulation input variables. The simulation code and sample outputs for each model can be found in Appendices C and D. Appendix E summarizes the simulation output results that include total variable costs, purchase costs, order costs, holding costs, backorder costs, disposal costs, and extension costs in table format. Appendix F is a detailed breakdown, including graphic displays, of the same data presented in Appendix E.

II. HAZARDOUS MATERIAL MANAGEMENT AND RELATED TOPICS

A. BACKGROUND

Until 1991, Navy units managed their hazardous material (HAZMAT) requirements independently in a decentralized manner. The primary responsibilities included safety in use and safe storage. Inventory related responsibilities involved determining proper inventory requirements, safety stock level, required order quantity, storage space needs, and the final disposal of any excess HAZMAT. Final disposal is considered either a transfer to another organization or the actual disposal of the hazardous waste. The consequence of this practice was an excess of material at the retail levels and, to meet the inflated retail demand, the wholesale level. This situation led to high holding costs of unneeded material, high disposal costs for excess and expired shelf-life material, and the levy of exorbitant fines.

In 1992 the Environmental Protection Agency (EPA) found a Navy command in violation of federal HAZMAT regulations relating to handling, storage and disposal. The initial EPA findings listed violations with fines totaling over $100,000 (Shide, 1995).

The solution to these problems was to consolidate the management of the HAZMAT and provide standardized guidance throughout the Navy. As early as June of 1989, with publication of OPNAVINST 4110.2, the Chief of Naval Operations charged the Naval Supply Systems Command (NAVSUP) with the management oversight of HAZMAT. In addition, the instruction established the Navy Hazardous Material Control and Management Program which defines policy, provides guidance, and identifies requirements for the life-cycle management of HAZMAT.

In January of 1991 Naval Air Weapons Station (NAWS) Point Mugu established a Hazardous Material Minimization Center (HAZMINCEN). The mission of the HAZMINCEN was to centralize management of HAZMAT for all commands at NAWS. The experience at Point Mugu was the genesis for the Consolidated Hazardous Material

Reutilization and Inventory Management Program (CHRIMP). The CHRIMP is a blueprint for reducing the quantity of HAZMAT, and maintaining positive control over each unit of a HAZMAT item from initial acquisition to final disposal. Due to the program's success at minimizing the quantity of HAZMAT through control of issues, centralized storage and disposal, and reuse of returned material at Point Mugu, NAVSUP adopted the model for future use by all Navy facilities.

The key to the success of Point Mugu's HAZMINCEN is centralized control of ordering, storage and disposal, and the reuse of leftover material when returned by a customer. If a customer chooses to use "leftover" material or, as it is now called, cost avoidance (CA) material, the Center issues it at no cost to the customer.

NAWS Point Mugu has a small number of commands that its HAZMINCEN serves. Would the concept work in a large geographic area? As the Navy's prototype, the Fleet Industrial Supply Center (FISC) at Puget Sound plans to set up a similar system in its surrounding geographic area. Their setup will include one HAZMAT Regional Control Center with up to fifteen local centers. These centers will serve the local customers for all of their HAZMAT requirements. Each center will be connected to the Regional Center via a computer network. This will enable the Regional Center to have total visibility over the entire HAZMAT inventory within the region. Although not designated as the prototype, FISC San Diego has a similar type operation in its geographical area.

The HAZMAT operations we discussed above each use the CHRIMP database program known as the Hazardous Inventory Control System (HICS). The HICS is used to assist in the inventory management of HAZMAT through receipt recording, inventory status, and generation of issue and disposal documents. The bar code system used with HICS allows tracking of each individual item.

B. SHELF-LIFE AND THE MANAGEMENT OF HAZARDOUS MATERIALS

The term "shelf-life" refers to material that physically deteriorates over time. An item's shelf-life means the length of time after procurement as new that an item can be issued and still be considered useful to the customer. When shelf-life material is held as inventory, the goal is to use it before its shelf-life expires. Once an item's shelf-life expires, it is no longer considered useful to the customer and must be disposed of, or tested to determine possible extension of its useful life. These two events generate costs, the cost of a shelf-life extension test, the cost of disposal, or both.

Shelf-life items have either a fixed life time or their life is based on external and random variables (e.g., environmental factors such as temperature, exposure to other chemicals or oxygen). The material covered in this study are items of a fixed life. The useful duration is known and it will remain so until the expiration date, unless the material is specified to be Type II and passes an extension test.

Either the designated inventory manager, the manufacturer, or another organization assigns an item's shelf-life based on an evaluation of the deteriorative and instability characteristics of the material. The shelf-life assignment is typically based on the military standards (MILSTD) for military material specifications (MILSPEC) or industry standards in the absence of MILSPECs.

Shelf-life material must remain under positive control throughout its life: from introduction into the supply system, to storage and issue, until final use or disposal. This active inventory management is occurring and growing in practice throughout the Navy because of the initiatives we described previously. The keys to minimizing the size and related disposal and extension costs of the shelf-life inventories are accurate demand forecasts, an issue policy adhering to either the material with the shortest shelf-life or the First-In-First-Out (FIFO) issue method, and following proper storage procedures. Other cost reducing practices include consolidating HAZMAT inventories in a single geographic area to serve all of the customers. Finally, the local HAZMINCTRs may use direct vendor

delivery to reduce retail level inventories and prevent excess stock levels.

Categories of shelf-life material include Types I and II. Type I cannot be extended beyond its assigned shelf-life. After the material's expiration, it is turned in for disposal to the Defense Reutilization Management Office (DRMO). Type II material may be extended after it has been inspected and tested. All Type II material has an individual maximum useful shelf-life, with 120 months being the longest time. When the material can no longer be extended, it must be disposed of like Type I material (DODINST 4140.27-M 1994).

C. PREVIOUS STUDIES RELATED TO HAZARDOUS MATERIAL INVENTORY MANAGEMENT

Piburn and Smith (1995) presented an analysis of the Hazardous Material Minimization Center Concept that is to be a Navy prototype. As mentioned above, it is located in the Puget Sound area of the state of Washington. The proposed mission of the Regional Hazardous Material Management Facility (HAZMATCEN) located at FISC Puget Sound is to optimize inventory levels, thus minimizing associated costs. This mission includes the eliminating the duplicate safety levels at the five supported HAZMIN sites and replacing them with one regional safety level located at the HAZMATCEN. The Center has examined the NAWS Point Mugu operation and adopted the successful practices of the operation (Wadlow, 1995).

Piburn and Smith also analyzed the suitability of the HICS to generate adequate data for inventory optimization and provided an analysis of data generated by HICS from the operation at Point Mugu. The study examined the components of and potential forecasting methods for demand and lead time and provided an analysis of the variable inventory management costs (i.e., ordering, holding, disposal, backorder, and transportation costs) associated with operating a HAZMATCEN. Finally, Piburn and Smith used the information to develop two mathematical inventory models that can be used to set reorder points and order quantities to minimize total variable costs for a given level of customer service. An overview of the these proposed models is presented in

Chapter III of this thesis. Piburn and Smith then recommended a pilot study involving an established customer to refine the study's forecasting and modeling techniques.

Murray (1995) presented an analysis of the current DoD shelf-life extension program. The study examined the methodology used to determine if a specific hazardous material managed by the DoD can be extended past normal expiration and the value gained by such an extension. The effect of the extension on inventory management and the cost/benefits regarding the shelf-life program costs to the related inventory savings were analyzed. Murray developed a HAZMAT inventory model for material with extendable shelf-life. The model was based on a stochastic version of the continuous review economic order quantity (EOQ) model that is commonly used for inventory management of consumable items where time-weighting of backorders is not critical. Details of this proposed model are reviewed in Chapter III of this thesis.

III. OVERVIEW OF OTHER PROPOSED MODELS

A. INTRODUCTION

In this chapter we will review three HAZMAT related models: Piburn and Smith's EOQ Model, Murray's EOQ model, and Piburn and Smith's version of Robillard's Modified Silver Model. At the end of the chapter, we will summarize each model's contributions to the HAZMAT inventory management challenge and our interpretations of each model.

B. THE STOCHASTIC ECONOMIC ORDER QUANTITY (EOQ) MODEL (PIBURN AND SMITH, 1994)

1. Model Development

a. EOQ Model Background

Ford Harris developed the EOQ model in 1915. It was a continuous review inventory model which assumed a deterministic demand for the items held in inventory. The order quantity which minimized total average annual variable costs (TVC) was called the "Economic Order Quantity." The model minimized TVC by balancing holding and ordering costs of inventory. The optimal order quantity equation follows:

$$Q^* = \sqrt{\frac{2DA}{H}},$$

where D = annual demand, units per year

A = ordering costs, and

H = annual holding cost per unit.

Due to the deterministic demand assumption, the model does not account for any demand uncertainty. Piburn and Smith incorporated this uncertainty into their model.

b. Piburn and Smith Assumptions

(1) Demand Probability Distribution is Known and Constant.

They assumed the demand rate to be probabilistic and described by a known probability distribution with a constant mean and variance over time. They considered this assumption to be valid after the HAZMATCEN and HAZMINCENs approached steady-state operations. Furthermore, they assumed the probability distribution for the demand rate to be Normal and independent of the lead time probability distribution.

(2) Lead time Probability Distribution is Known and Constant.

Piburn and Smith assumed lead times to be probabilistic since the General Services Administration (GSA) and the Defense Logistics Agency (DLA) cannot be relied upon to provide material in any consistent time frame. The probability distribution for lead time was assumed to be Normal.

(3) Instantaneous Receipt.

All units of a replenishment order, regardless of order size, are received at the same time.

(4) No Quantity Discounts are Available.

The DOD Supply System providing "A" condition material to a HAZMINCEN does not offer quantity discounts.

(5) All Costs are Known and Constant.

All costs were assumed to be known and would not change appreciably over the demand period.

(6) Disposals will be a Factor of Returned Material.

This assumption is not included in either the original EOQ model or any current Navy inventory models. The actual disposal rate is a random variable dependent on the amount of "A" condition and CA material, but due to lack of historical data they assumed the rate to be a constant fixed percentage of returned material only.

c. *The Model*

(1) Notation used in Deriving Reorder Point.

$\mathbf{D_{MRP}}$	- Mean MRP demand rate, units per day;
$\mathbf{D_{NM}}$	- Mean non-MRP demand rate, units per day;
$\mathbf{D}$	- Mean total demand rate, units per day;
$\mathbf{W}$	- Mean return rate, units per day;
$\mathbf{d_r}$	- Decimal fraction of returns going to disposal per day;
$\mathbf{D_{MRPLT}}$	- Mean MRP demand during lead time, units;
$\mathbf{D_{NMLT}}$	- Mean non-MRP demand during lead time, units;
$\mathbf{D_{LT}}$	- Mean total demand during lead time, units;
$\mathbf{W_{LT}}$	- Mean returns during lead time, units;
$\mathbf{DIS_{LT}}$	- Mean disposal quantity during lead time, units;
$\mathbf{LT}$	- Procurement lead time, days;
$\boldsymbol{\sigma_{MRP}}$	- Standard deviation of MRP demand rate, units per day;
$\boldsymbol{\sigma_{NM}}$	- Standard deviation of non-MRP demand rate, units per day;
$\boldsymbol{\sigma_{D}}$	- Standard deviation of total demand rate, units per day;
$\boldsymbol{\sigma_{W}}$	- Standard deviation of return rate, units per day;
$\boldsymbol{\sigma_{LT}}$	- Standard deviation of lead time, days;
$\boldsymbol{\sigma_{MRPLT}}$	- Standard deviation of MRP lead time demand, units;
$\boldsymbol{\sigma_{NMLT}}$	- Standard deviation of non-MRP lead time demand, units;
$\boldsymbol{\sigma_{LTD}}$	- Standard deviation of total lead time demand, units;

σ_{WLT} - Standard deviation of returns during lead time, units;

σ_{DISLT} - Standard deviation of disposals during lead time, units;

z - Standard normal deviate;

SS - Safety Stock;

ROP - Reorder Point for the HAZMATCTR.

(2) Derivation of the Reorder Point.

Piburn and Smith defined the Mean total demand rate (D) and Mean total demand during lead time (D_{LT}) using the following equations. They also defined mean returns during lead time (W_{LT}) and mean disposals during lead time (DIS_{LT}) as defined below:

$$\mathbf{D = D_{MRP} + D_{NM}}\ ;$$

$$\mathbf{D_{MRPLT} = D_{MRP}\ LT}\ ;$$

$$\mathbf{D_{NMLT} = D_{NM}\ LT}\ ;$$

$$\mathbf{W_{LT} = W\ LT}\ ;$$

$$\mathbf{DIS_{LT} = d_r\ W_{LT}}\ ;$$

and, therefore,

$$\mathbf{D_{LT} = D_{MRPLT} + D_{NMLT} - W_{LT} + DIS_{LT} = D\ LT.}$$

Next, they defined the standard deviations for the components. Tersine's formula for the standard deviation for demand during lead time under the assumption of Normality is (Tersine, 1994):

$$\sigma = \sqrt{D^2 \sigma_{LT}^2 + LT \sigma_D^2}\ .$$

The equations for determining the standard deviation for the different demands are thus:

$$\sigma_{MRPLT} = \sqrt{D_{MRP}^2 \sigma_{LT}^2 + LT \sigma_{MRP}^2}\ ;$$

$$\sigma_{NMLT} = \sqrt{D_{NM}^2 \sigma_{LT}^2 + LT \sigma_{NM}^2} \quad ;$$

$$\sigma_{WLT} = \sqrt{W^2 \sigma_{LT}^2 + LT \sigma_W^2} \quad ;$$

$$\sigma_{DISLT} = \sqrt{d_r^2 \sigma_{WLT}^2} \quad .$$

The variance of a sum of independent random variables is the sum of the variances, therefore:

$$\sigma_{LTD} = \sqrt{\sigma_{MRPLT}^2 + \sigma_{NMLT}^2 + (1 + d_r^2) \sigma_{WLT}^2} \quad .$$

The Reorder Point (ROP) or Low Limit for their model is the average demand during procurement lead time plus a level of safety stock based on the customer's preferred service level. Safety stock accounts for the unknown random component of demand. Safety stock inventory is the expected net inventory at the time a replenishment arrives. A positive safety stock is kept on hand as a cushion against stockouts due to the random nature of demand during lead time (Tersine, 1994, p. 206). The safety stock held in inventory is based on an inventory level that makes the level of risk (probability of a stockout during procurement lead time) acceptable. For the Normal distribution, Tersine expressed ROP as follows:

$$\mathbf{ROP = D_{LT} + z\sigma_{LTD}} \quad ;$$

where $\mathbf{z\sigma_{LTD}}$ is the safety stock (SS).

Piburn and Smith used this equation to derive the HAZMATCEN's reorder point:

$$\mathbf{ROP = D_{MRPLT} + D_{NMLT} - W_{LT} + DIS_{LT} + SS.}$$

where,

$$SS = Safety\ Stock = z \sqrt{\sigma_{MRPLT}^2 + \sigma_{NMLT}^2 + (1 + d_r^2) \sigma_{WLT}^2}$$

(3) **Notation used in Deriving the Order Quantity.**

- **Q** - Order quantity, units
- $\mathbf{C_P}$ - Procurement cost of the item, dollar per unit
- $\mathbf{C_D}$ - Cost of disposal, dollar per unit
- **R** - Mean annual demand, units per year
- **Y** - Mean annual returned quantity (equal to the mean daily return rate, **W**, times the number of working days per year of at least 260 days.), units
- **I** - Annual holding cost fraction, as a percent of item unit cost
- **A** - Cost per order, dollars.
- $\boldsymbol{\lambda}$ - Cost of a backorder, dollar per unit.

Piburn and Smith stated that $\boldsymbol{\lambda}$ is implied by the desired risk of stockout (RISK). They defined desired customer service level as (1 - RISK).

(4) **Order Quantity.**

As with the original EOQ model, the optimal order quantity for this model is dependent upon the average annual total variable costs (TVC). The goal of Piburn and Smith was to find the order quantity that minimizes TVC. In their model, the TVC equation is:

TVC = Purchase Costs + Ordering Costs + Holding Costs + Backorder Costs + Disposal Costs;

The five average annual variable costs components of TVC were developed using the following logic:

(a) **Purchase Costs.** The average annual Purchase Cost are the product of unit cost of the item and the net annual average demand for "A" condition material. This cost is dependent on yearly demand and is not a function of Order Quantity (Q). Piburn and Smith assumed the HAZMATCTR would be able to meet

the customer's average annual demand. The equation for average annual purchase costs is therefore:

$$C_P[R - Y(1 - d_r)] \quad .$$

(b) Ordering Costs. The average annual Ordering Costs for "A" condition material are the product of the cost per order and the average number of order cycles per year. The number of order cycles per year is found by taking the net average annual demand and dividing it by the order quantity. The result is:

$$A\,[\frac{R - Y(1 - d_r)}{Q}] \quad .$$

(c) Holding Costs. The average annual Holding Costs are the product of the average annual on-hand inventory and the annual holding cost per unit. The average annual on-hand inventory is equal to the sum of the safety stock and one half of the order quantity. Annual holding cost per unit equals the annual holding cost fraction multiplied by the unit cost of each item. The cost of inspecting material for expired shelf-life was assumed to be part of the holding cost per unit.

$$IC_P[\frac{Q}{2} + SS].$$

(d) Backorder Costs. Let E(LTD > ROP) represent the expected amount that demand during procurement lead time, LTD, will exceed the reorder point The average annual Backorder Costs are then the product of the cost of a backorder multiplied by the expected number of backorders likely to occur during a procurement lead time, E(LTD > ROP). This product is then multiplied by the average number of order cycles that occur per year to determine the annual cost. The result is:

$$\lambda \left[\frac{R - Y(1 - d_r)}{Q}\right] [E(LTD > ROP)],$$

The equation for E(LTD > ROP) under the assumption of a Normal distribution for demand during lead time is:

$$E(LTD > ROP) = \sigma_{LTD}(f(z) - z P(LTD > ROP)).$$

In this equation f(z) is the density function of the standardized Normal distribution (i.e., mean is zero, and the standard deviation is 1).

(e) Disposal Costs. These costs apply to the disposal of CA material. The average annual Disposal Costs are the product of the cost of disposal for each item multiplied by the average amount of material disposed of per year. Since Piburn and Smith assumed this amount is a fixed percentage of the amount of material returned, the equation is:

$$C_D Y d_r \quad .$$

(f) Total Average Annual Variable Costs. Substituting the above cost component equations into the Total Average Annual Variable Cost equation given above results in:

$$TVC = C_P [R - Y(1 - d_r)] + A \left[\frac{R - Y(1 - d_r)}{Q}\right]$$

$$+ IC_P \left[\frac{Q}{2} + SS\right] + C_D Y d_r + \lambda \left[\frac{R - Y(1 - d_r)}{Q}\right] [E(LTD > ROP)].$$

(g) Determining the Optimal Order Quantity. Taking the first derivative of TVC with respect to Q, setting it equal to zero, and solving for Q

results in the following equation for the Optimal Order Quantity:

$$Q = \sqrt{\frac{2\,[R - Y(1 - d_r)]\,[A + \lambda E(LTD > ROP)]}{IC_P}}.$$

(h) High Limit. The high limit, sometimes called the requisitioning objective, is the sum of the Reorder Point (Low Limit) equation and the optimal Order Quantity:

HIGH LIMIT = ROP + Q.

C. THE STOCHASTIC ECONOMIC ORDER QUANTITY (EOQ) MODEL USING SHELF-LIFE FACTORS (MURRAY, 1995)

1. Model Development

a. Background

The background for Murray's EOQ model is the same as for Piburn and Smith's EOQ model. The goal is to minimize total average annual variable costs. We will not repeat duplicate assumptions and notation between the two models. We have also standardized the notation of Murray's model to match that of the Piburn and Smith model.

b. Harris EOQ Model Assumptions with Murray's Modifications

(1) Lead Time is known and constant.

Unlike Piburn and Smith, Murray argued that lead time can be controlled through wholesale supplier relations and considerably shortened with the use of direct vendor delivery for stockout material requiring backorder. Thus, it can be assumed to be known and constant.

(2) Shelf-life material in inventory will have a known expiration that can be extended.

Unique to Murray's model is that the material in the inventory can

have expiration dates. The item manager can designate this shelf-life by using a standard shelf-life code. Expiration dates may be extended as a consequence of testing. This has the advantage of reducing the amount of hazardous material waste generated and decreases the demand for new material. Murray does not consider CA material, however.

c. *The Model*

Minimizing the expected TVC with respect to the decision variables will result in the optimal order quantity and reorder point. Murray's TVC equation is:

TVC = Purchase Costs + Ordering Costs + Holding Costs + Backorder Costs +Disposal Costs + Extension Costs

(1) Murray Model Unique Notation.

- $\mathbf{C_t}$ - Cost of a shelf-life material extension (testing, segregation and labeling costs);
- $\mathbf{N_t}$ - Expected annual number of shelf-life extension tests;
- $\mathbf{X_d}$ - Expected shelf-life inventory quantity disposed to expiration per year, units;
- $\mathbf{X_e}$ - Expected shelf-life inventory quantity extended per year, units;
- $\mathbf{I}$ - Annual holding cost rate (the notation is repeated here since Murray includes expired material awaiting disposal or salvage in this factor).

The five annual variable cost components of TVC were each derived as follows.

(a) Purchase Costs. The costs to purchase "A" condition inventory are the product of the cost per unit and the expected net annual demand. Net annual demand is the annual customer demand plus the annual amount of expired material

disposed of less the amount of shelf-life material extended. The equation is:

$$C_P(R + X_d - X_e).$$

(b) Ordering Costs. The ordering costs are the product of cost per order and the expected number of orders placed per year. The expected number of orders placed during the year is the expected net annual demand experienced throughout the year divided by the order quantity. The equation is:

$$A\,[\frac{(R + X_d - X_e)}{Q}].$$

(c) Holding Costs. The holding costs are the product of the average on hand inventory and the annual holding cost per unit held as inventory. The annual holding cost is the annual holding cost rate multiplied by the unit procurement cost of the inventory. The average on hand inventory is the sum of the order quantity and shelf-life inventory quantity, divided by two, and the safety stock level. The equation is:

$$IC_P\,[\frac{(Q + X_e)}{2} + SS].$$

(d) Backorder Costs. The backorder costs are the product of the cost of a backordered unit and the expected number of backorders during the procurement lead time. This product is multiplied by the number of reorder cycles per year to obtain the expected annual backorder costs. The equation is:

$$\lambda\,[\frac{(R + X_d - X_e)}{Q}]\,[E(LTD > ROP)].$$

(e) Disposal Costs. The disposal costs are the product of

the cost of disposal per unit and the expected quantity of units disposed per year due to shelf-life expiration. The equation is:

$$C_D\,(X_d).$$

(f) Extension Costs. The extension costs are the costs incurred for testing extension-candidate material. They are the product of the cost per test and the expected number of tests conducted per year. The equation is:

$$C_t\,(N_t).$$

Murray elaborates that N_t is implicitly a factor of the feasibility of the test based on the cost of the test(s) required, quantity, and value of the material being tested.

(g) Reorder Point. The ROP is the sum of the average demand during the procurement lead time and the desired safety stock. The safety stock quantity is typically based on the service level and customer requirements. If demand is Normally distributed, then the ROP equation is:

$$ROP = D_{LT} + z\,\sigma_{LTD},$$

therefore,

$$SS = z\,\sigma_{LTD}.$$

The expected Total Annual Variable Costs equation as a function of order quantity and reporder point is then determined by substituting the component equations of the six previous sections into the TVC equation. The result is:

$$TVC = C_P(R + X_d - X_e) + A\left[\frac{(R + X_d - X_e)}{Q}\right]$$

$$+ IC_P\left[\frac{(Q + X_e)}{2} + SS\right] + \lambda\left[\frac{(R + X_d - X_e)}{Q}\right][E(LTD > ROP)]$$

$$+ C_D(X_d) + C_t(N_t).$$

Taking the first derivative of TVC with respect to Q, setting it equal to zero, and solving for Q results in the following equation for the Optimal Order Quantity:

$$Q = \sqrt{\frac{2\,[R + X_d - X_e]\,[A + \lambda E(LTD > ROP)]}{I C_P}}.$$

The optimal value for the reorder point is found by taking the first derivative of the TVC with respect to ROP (Note that SS = ROP - D_{LT} in the TVC equation). This calculation results in the equation for the risk of stockout:

$$RISK = P[LTD > ROP] = \frac{QIC_P}{\lambda(R + X_d - X_e)}.$$

The value of the risk of stockout is then used to determine **z** from the Normal table. Once **z** has been identified, ROP and E(LTD > ROP) can be computed. However if the cost of a backorder, **λ**, is not known the RISK formula must be used to determine it. Therefore, a service level or risk value must be designated. Using that service level and Q, a value of of E(LTD > ROP) can be calculated from,

$$E(LTD > ROP) = Q(1 - Service\ Level).$$

Murray states that since the optimal Q and P(LTD > ROP) formulas contain both Q and ROP, an iterative process is needed to find the optimal Q and ROP. The first step

is to find an initial Q using the following formula:

$$Q = \sqrt{\frac{2\,[R + X_d - X_e]\,A}{IC_P}}.$$

Q is then used in the preceding formula to determine E(LTD > ROP).

As mentioned in the discussion of the Piburn and Smith model, if lead time demand is Normally distributed and the Normal deviate, z, is known, then the following equation can be used to determine the associated value of E(LTD > ROP).

$$E\,(LTD > ROP) = \sigma_{LT}\,(f(z) - zP(D_{LT} > ROP)).$$

If λ is not known then at this point z is also not known. Since z is not known, but E(LTD > ROP) is, this equation can be used to determine z. As Murray stated, the procedure for finding z is to assume successive z values and compute the E(LTD > ROP) for each z until a value of z is found that gives the same E(LTD > ROP) as was computed from a previous equation, namely; $E(D_{LT} > ROP) = Q(1 - \text{Service Level})$. During the procedure, the corresponding P(LTD > ROP) value can easily be determined from the complementary cumulative distribution function for the standardized Normal distribution for any given z value. If a table of successive z and corresponding P(LTD > ROP) values is developed, it can be used in later iterations to reduce the subsequent search times for the new z values.

Finally, to determine λ, substitute the value for P(LTD > ROP) into the optimal risk formula and solve for λ. The equation for λ becomes:

$$\lambda = \frac{QIC_P}{P\,[LTD > ROP]\,(R + X_d - X_e)}.$$

This **λ** value is used in the optimal EOQ equation below to derive the next Q value.

$$Q = \sqrt{\frac{2\,[R + X_d - X_e]\,[A + \lambda E(LTD > ROP)]}{IC_P}}.$$

The next step is to find a new E(LTD > ROP) and λ. The process continues until the values of Q stop changing.

Finally, the ROP value is :

$$ROP = D_{LT} + z\sigma_{LTD},$$

where **z** is the final value of the Normal deviate from the iterative process. Finally, the high limit can be calculated using the following equation:

$$HIGH\ LIMIT = ROP + Q.$$

D. THE MODIFIED SILVER MODEL (Robillard, 1994)

1. Model Development

a. Background

Piburn and Smith also examined the Modified Silver model developed by Robillard (1994). This model is based on a periodic review in contrast to the previous two continuous review models. The Silver model is a lot-sizing algorithm based on the least total variable costs per unit time approach (Silver, 1978). The model addresses the problem of determining the timing and size of replenishment of an item having probabilistic demand with a varying mean over time. It assumes a known replenishment lead time of a specific period.

Robillard adjusted the model to allow for lead times being stochastic vice deterministic (Robillard, 1994). His model, the "Mod-Silver," is similar to a periodic review model because he assumes a fixed time between reviews of the current inventory position.

b. Assumptions

(1) Calendar time is divided into fixed time periods of the same length. Reviews will be conducted at the end of each period and orders arrive at the start of a period.

(2) Procurement lead time is Normally distributed and the mean and standard deviation can be estimated.

(3) Demand forecasts exist for each period in a specified forecast time horizon. The length of the forecast horizon is constrained by the DoD constraint which limits the maximum reorder amount to the expected demand over six quarters. Piburn and Smith assumed review periods of one week, therefore this figure became 78 weeks (6 quarters multiplied by 13 weeks per quarter).

(4) The selection of a reorder point does not depend on the value of maximum inventory position to be used. Instead, it depends on the determination that adequate service can be provided if the placing of an order is delayed until at least the next review point.

(5) Demand forecasts errors are Normally distributed for a time interval equal to the mean lead time plus one fixed review period

(6) Holding and ordering costs are the only relevant costs. Like the Silver model, holding costs are charged only on inventory carried from one period to another.

(7) Demand occurs at the beginning of each review period so no holding cost is incurred on this material during the period immediately following the review.

(8) Safety stock is determined based on a desired customer service level. This stock acts as a buffer against larger-than-expected lead time demand.

(9) Outstanding orders do not cross in time; orders are received sequentially.

Since Robillard's model does not include holding costs of returned material, disposal costs, and shortage costs, Piburn and Smith added the following assumptions to the Mod-Silver model to account for these costs.

(10) The return of CA material occurs at the beginning of each review period.

(11) Disposals occur before the returned material is brought back into stock. Therefore, no holding cost is incurred on disposed material.

(12) Forecasts for returns exist for each period in a specified forecast time horizon.

(13) The quantity of returns is Normally distributed for a time interval equal to the mean lead time plus one fixed review period.

(14) Shortage costs exist but are unknown; they are solved for implicitly after specifying a level of service.

c. *The Model*

(1) Notation.

The parameter definitions from section A.1.c. (1) remain a part of this model. The following new parameters were introduced by Robillard:

- $\mathbf{t_0}$ - Time of the current review;
- **IP** - Inventory position at the time of the current review, units;
- **L** - Mean lead time in weekly periods;
- **T** - Order interval, the number of periods that the current order is expected to cover (an integer number of weeks);
- $\mathbf{k_a}$ - Actual safety stock factor based on the current inventory position if an order is not placed (a Normal deviate);
- $\mathbf{k_r}$ - Required safety stock factor (set by policy) at the current review point to meet demand for L + 1 periods (a Normal deviate);
- $\boldsymbol{\Upsilon}$ - Random variable that represents lead time;
- **X1** - Forecasted demand over the time interval t_0 to L + 1 units;
- **X2** - Forecasted demand over the time interval t_0 to T - 1, units;
- **X3** - Forecasted demand over the time interval T - 1 to L + T,

units;

σ_i - Standard deviation of demand forecast error for the i_{th} period, units;

σ_{X1} - Standard deviation of demand forecast error over the time interval X1, units;

σ_{X2} - Standard deviation of demand forecast error over the time interval X2, units;

σ_{X3} - Standard deviation of demand forecast error over the time interval X3, units;

b - Safety stock coefficient (factor of X2);

c - Coefficient of variation;

d_i - Forecasted demand for the i_{th} period, units;

$\bar{d}_{X1}$ - Average demand for the time interval X1, units;

σ_Y^2 - Variance of procurement lead time.

Figure 3.1 illustrates the different time intervals of Robillard's Mod-Silver model.

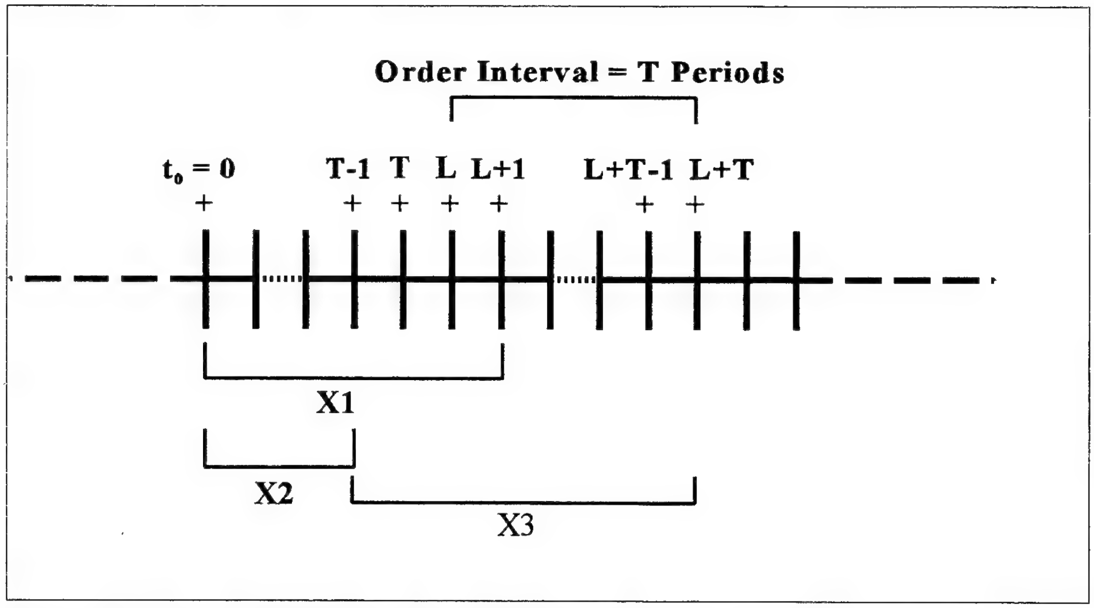

Figure 3.1. Time Sequence, Forecast Intervals, and Forecasted Demand.

(2) Reorder Point.

This model is based on a periodic review system, therefore it is important to determine the probability of a stockout at the time of the review. This probability is based on the following logic. If an order is not placed at time t_0, the current inventory position (IP) must be able to provide for actual demand during a time interval of length L+1, which is the expected order receipt if an order is not placed until the next review (t_0+1). According to Robillard, the actual safety factor can be evaluated with the following equation:

$$k_a = \frac{IP - X1}{\sigma_{X1}}.$$

The required safety factor, k_r, is dependent on the service level specified by the item manager per Robillard. An order should be placed at the current review if k_a is less than k_r at t_0. This situation implies that the current IP is insufficient to provide the desired level of service for the next L+1 periods. The standard deviation of

demand over the aforementioned period can be expressed as:

$$\sigma_{X1} = \sqrt{\sum_{i=1}^{L+1} \sigma_i^2 + \bar{d}_{X1}^2 \sigma_{\Upsilon}^2} \ ,$$

where i=1 is the first period following t_0.

(3) Order Interval.

The Order Interval is determined by the use of the Silver-Meal heuristic (Silver and Peterson, 1978). The heuristic selects the lowest integer value of T such that the total relevant costs per unit time for the duration of the replenishment quantity are minimized. The replenishment quantity is the total demand during the interval that the current order is expected to cover. The Total Relevant Costs per unit time is defined by the following equation where **I** is now the weekly holding cost rate:

$$TRCUT(T) = \frac{A + IC_p \sum_{i=1}^{T} (i - 1) d_i}{T} .$$

The Silver-Meal heuristic selects T corresponding to the first minimum that occurs for TRCUT. Thus, the global minimum may not be attained. However, Robillard set up the Mod-Silver model to select the value of T that minimizes TRCUT(T) from among all the values from 1 to 78. This guarantees a minimum over the constrained forecast horizon of 78 weeks (Robillard, 1994).

(4) Order Quantity.

The Order Quantity (Q) and therefore the High Limit are dependent on the length of the order cycle (T). Robillard explained that two distinct possibilities exist, T equals one review period, or T is greater than one review period.

When the order cycle is one period (T=1), the Order Quantity is as follows:

$$Q = X1 + k_r \sigma_{X1} - IP.$$

This equals the sum of the expected average demand for the interval and the required safety level minus the inventory position at the current review. Figure 3.2 provides an illustrated example of the order interval (Robillard, 1994).

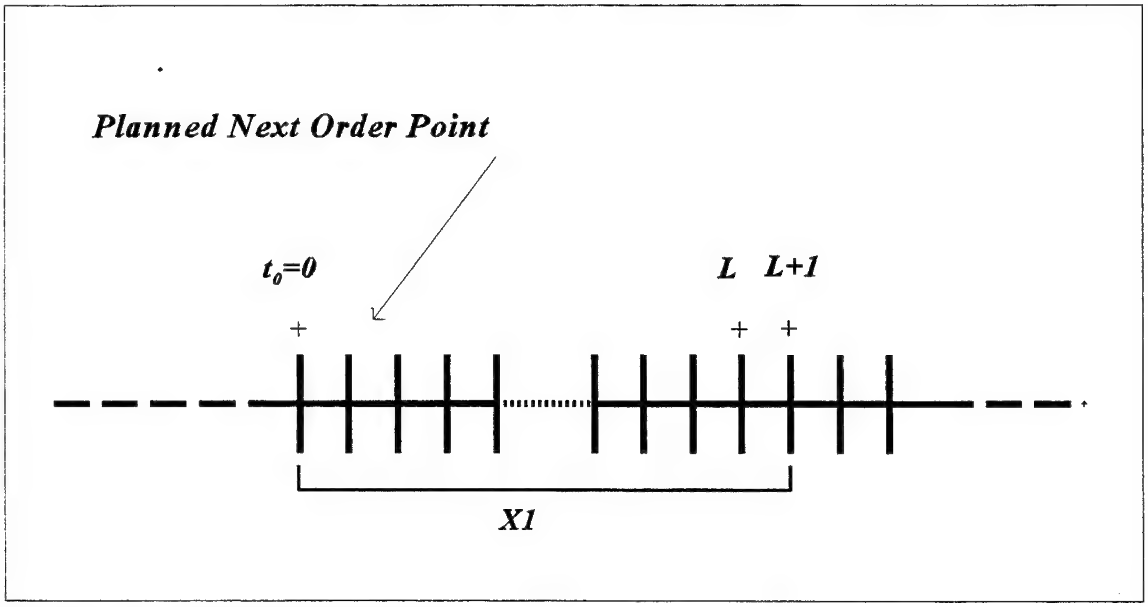

Figure 3.2. Order Interval for T=1.

The situation when the order interval is greater than one period (T>1) is shown in Figure 3.3. As stated by Piburn and Smith, the model needs to account for the possibility that, although the next order is planned at T periods after the current period, during the periodic reviews a situation is reached where $k_a < k_r$ at a time less than T. This would require a small order to be placed at that time. To reduce the chance for this situation, the model has a safety cushion that is a multiple of the standard deviation of the interval of concern, X2. Robillard expressed the Order Quantity for this situation as follows:

$$Q = (X2 + b\sigma_{X2}) + (X3 + k_r \sigma_{X3}) - IP.$$

The factors of the above equation are defined as follows:

$X2 + b\,\sigma_{X2}$ is the expected demand plus safety stock for the interval t_0 to T-1; this is the period up to, but not including, the next planned reorder review. The additional safety stock cushion, a multiple, **b**, is the measure of uncertainty of forecast errors over this time interval. The normal deviate **b** value is set by the activity that must determine how much additional safety stock cushion is required to prevent the possibility of numerous stockouts.

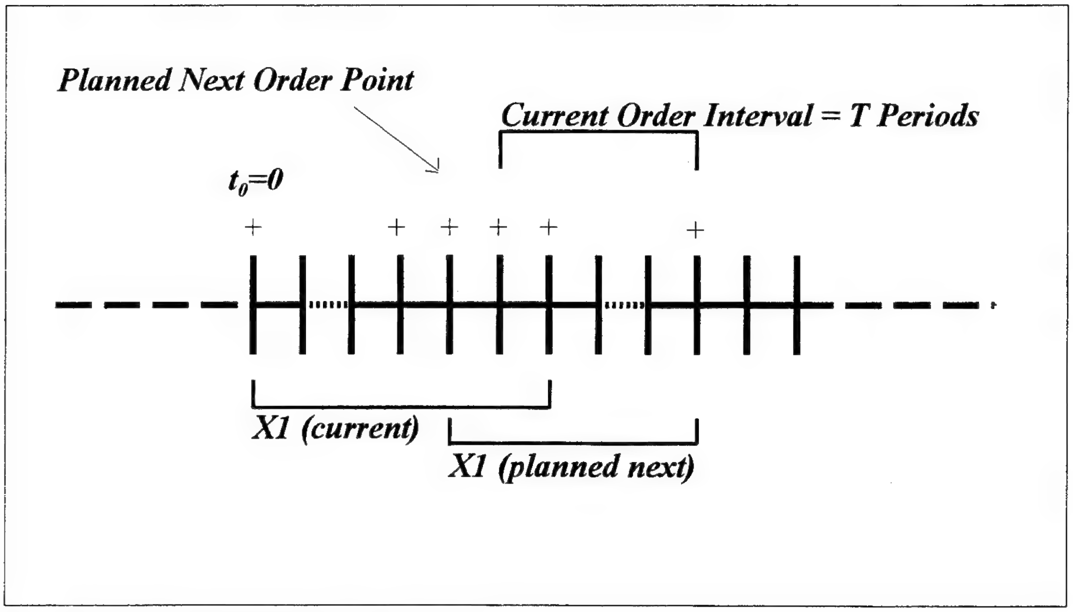

Figure 3.3. Order Interval for T > 1.

$X3 + k_r\sigma_{X3}$ is the forecasted demand plus safety stock over the interval T-1 to L+T; this is the interval from just prior to the next planned reorder to the expected delivery of the next planned reorder. In this case, safety stock is the product of the required safety factor and the standard deviation of the forecast over this time interval.

Robillard approximated the standard deviations corresponding to the intervals X1, X2, and X3 as follows:

$$\sigma_{X1} = \sqrt{c^2 \sum_{i=1}^{L+1} d_i^2 + \bar{d}_{X1}^2 \sigma_\Upsilon^2},$$

$$\sigma_{X2} = c\sqrt{d_1^2 + d_2^2 + \ldots + d_{T-1}^2},$$

$$\sigma_{X3} = \sqrt{c^2 \sum_{i=1}^{L+T} d_i^2 + \bar{d}_{X3}^2 \sigma_\Upsilon^2}.$$

These equations represent the degree to which there is potential error in the forecast for each of these intervals. Robillard stated that these estimates assume that the coefficient of variation, or the ratio of the standard deviation of forecast error of a single period to its mean (forecast), is constant over the forecast horizon. The estimate of the coefficient of variation, **c**, can be expressed as follows:

$$c = \frac{1.25\,(MAD_1)}{d_1},$$

where $\mathbf{MAD_1}$ represents the forecast mean absolute deviation of demand for the next period and $\mathbf{d_1}$ is the next period's demand forecast.

d. *Piburn and Smith's Relating of the Model to the HAZMATCEN*

Piburn and Smith addressed several issues so that the Mod-Silver model could be made applicable to the HAZMATCEN concept.

(1) Low Variability of Demand.

Due to the lack of useful data, Smith and Piburn could not make accurate demand forecasts. They assumed that a near steady state expected demand would evolve as MRP requirements became the core of customer activity. However, as Piburn and Smith pointed out, some random demand will still be expected to exist.

(2) Net Mean Demand Per Period.

Average (mean) demand per period must be forecast for "A" condition material. Forecasts of the average return rate per period and the average disposal rate per period of CA material is also required. They assumed that the disposal rate was a fixed percentage of returns. They then adjusted the CA material to reflect the fixed percentage of material that would be disposed of.

Net mean demand per period (**d_i***) is the mean demand for "A" condition material less the mean amount of this demand that is satisfied with CA material that has been received back from customers. The equation for **d_i*** is:

$$d_i^* = d_i - w_{i-1}(1 - d_r).$$

In the previous equation, **d_i** represents the forecasted expected demand for "A" condition material for the period **i** and **w_{i-1}** represents the expected CA returns for period **i-1**. Smith and Piburn reasoned that since unused material is to be returned to the HAZMINCEN within one week, the material should be available to fulfill demand requirements during the next period. This is the reason for the **i - 1** subscript.

(3) Costs.

Since, as previously mentioned, Robillard's model omits HAZMAT problem relevant costs, Piburn and Smith suggested three additional cost components for the TRCUT(T) equation.

(a) Holding Costs. They revised the holding cost term of the TRCUT(T) equation to account for material that is returned. The equation is:

$$IC_P[\sum_{i=1}^{T} (i - 1)|d_i^*|].$$

The absolute value of d_i^* accounts for periods when mean returns exceed mean demands.

During periods when returns exceed demand no additional material will be ordered but holding costs will still be incurred since the CA material is not being disposed of.

(b) Disposal Costs. Piburn and Smith treated disposal costs like holding costs. In a steady state, disposal costs should approach zero due to the improved planning by the HAZMATCEN customers. However, this situation is unlikely. In addition, the marginal cost to dispose of an unit of material is expected to continue to rise. The equation is:

$$C_D \sum_{i=1}^{T} (w_{i-1}) d_r .$$

(c) Shortage Costs. The expected quantity of the material short can be expressed by the following formula:

$$\lambda\, [E(\sum_{i=1}^{L+T} d_i^* > [(X2 + b\sigma_{X2}) + (X3 + k_r \sigma_{X3})])] .$$

Piburn and Smith considered λ to be an implied cost of stockout for a given item. They then multiplied this cost by the expected number of stockouts from the time of the review to the receipt of the next planned order (the interval L+T). The terms of the above equation are defined below:

$\sum_{i=1}^{L+T} d_i^*$ - the cumulative net demand between the time of the order to the receipt of the next planned reorder.

$[(X2 + b\sigma_{X2}) + (X3 + k_r \sigma_{X3})]$ - mean expected demand from the interval t_0 to L+T plus the safety stock cushions for that period. This is the value of the desired maximum inventory level at time t_0.

(4) Proposed Adjusted TRCUT(T) Equation

The Piburn and Smith proposed TRCUT(T) formula with the additional cost factors included is:

$$TRCUT(T) = \frac{A + IC_P[\sum_{i=1}^{T} (i - 1)|d_i^*|] + C_D[\sum_{i=1}^{T} (w_{i-1})d_r] + \lambda[E\sum_{i=1}^{L+T} d_i^* > (X2 + b\sigma_{X2}) + (X3 + k_r\sigma_{X3}))]}{T}$$

E. SUMMARY

This chapter has presented an overview of three previously proposed HAZMAT inventory models. The first was an EOQ or continuous review type of model developed by Piburn and Smith that allowed for a probabilistic demand rate, probabilistic lead time, and disposal quantities being a factor of returned material. This model included a mean annual return quantity, **Y**, which is in good enough condition to be issued at no cost to a customer (i.e., CA material). That CA material was incorporated into the equations for determining purchase costs, ordering costs, backorder costs, and disposal costs. However, the model fails to account for the costs of extending the shelf-life of material.

Murray's was the second EOQ or continuous review type of model discussed. His assumptions differed from Piburn and Smith in that while the demand rate was probabilistic the lead time was known. His model has the same major inventory costs as the Piburn and Smith model, but the equations for each cost differed in that they did not consider CA material. Murray did include a cost term for the expected shelf-life extension costs. A major assumption was that shelf-life material with a known expiration date could be extended according to a particular item's extension test requirements. However, upon the expiration of the HAZMAT's shelf-life, there will always be an associated extension cost.

The final model examined was Piburn and Smith's version of Robillard's Mod-Silver model. The model is based on Silver's periodic review model. The difference in the number of and type of assumptions between Piburn and Smith's continuous model and the

periodic model are noteworthy. The first nine model assumptions pertain to the model being periodic. Only the key points of each assumption are repeated here:

1) calendar time is divided into fixed time periods of the same length,

2) procurement lead time is Normally distributed.

3) demand forecasts exist for each period in a specified forecast horizon,

4) the selection of a reorder point does not depend on the value of maximum inventory position to be used,

5) demand forecast errors are Normally distributed,

6) holding and ordering costs are the only relevant costs,

7) demand occurs at the beginning of each review period,

8) safety stock is determined based on a desired customer service level, and

9) outstanding orders do not cross in time.

The remainder of the assumptions relate to unique issues of managing HAZMAT and identifying shortage costs. These final assumptions are:

10) the return of CA material occurs just before the beginning of each review period,

11) disposals occur before the returned material is brought back into stock,

12) forecasts for returns exist for each period in a specified forecast time horizon,

13) the quantity of returns is Normally distributed, and

14) shortage costs exist but are unknown.

This model does not consider the cost of extending material.

In the following chapters, we will develop a continuous review EOQ model and a periodic review model. These models will be based on the three discussed in this chapter. The models will each be revised to include the standard inventory costs (i.e., purchase, order, holding, and backorder costs) plus the HAZMAT inventory costs (i.e., disposal and extension costs). CA material will also be a factor of demand in each model.

Using simulation, we will evaluate the two revised models to determine which

model results in a lower annual TVC for an item of HAZMAT. Subsequent simulations of the same item will be embellished to include these changes:

(1) Quantity of available CA material;

(2) Shelf-life length;

(3) Percentage of customers willing to accept CA material in lieu of "A" condition material;

(4) Percent of material that fails its extension test.

Each of the embellishments will also be evaluated using the resulting TVC value.

IV. SHELF-LIFE MODEL DEVELOPMENT

A. INTRODUCTION

The models developed in this chapter provide a choice of either a continuous review inventory model or a periodic review inventory model which include all relevant costs; namely, costs for ordering, holding, disposal, and extension. These models are more comprehensive with regard to total costs than the previously proposed models.

Chapter III reviewed the previously proposed shelf-life inventory models presented by Piburn and Smith (1994) and Murray (1995). Murray modified the stochastic version of the classic EOQ continuous review model by adding shelf-life extension costs to the total annual variable cost calculation but he did not consider CA material. He also presented a cost-based evaluation formula to determine whether or not eligible shelf-life material should be tested for extension upon expiration or simply disposed of as hazardous waste. This cost-based evaluation formula is modified in Subsection E of this chapter to facilitate its use with a periodic review inventory model as well as a continuous review inventory model. One model developed in this chapter modifies Murray's EOQ model to consider CA material. The other model developed in this chapter incorporates shelf-life extension factors into the Modified Silver model presented by Piburn and Smith. A service level is assumed to be specified and an implied cost of stockout is then calculated, as Murray did, since the military has been unable to determine realistic shortage costs for any consumable material.

B. THE ECONOMIC ORDER QUANTITY MODEL WITH COST AVOIDANCE MATERIAL ENHANCEMENTS

1. Background

An inventory model designed for use by a HAZMINCEN should incorporate all relevant costs and factors related to HAZMAT management. As noted in Chapter III, Piburn and Smith considered the impact of CA material in the development of their EOQ model. Murray considered shelf-life extension costs and disposals, but disregarded the

impact of CA material. The EOQ model developed in this section expands Murray's EOQ model by incorporating CA material in an attempt to include all costs relevant to the management of HAZMAT. This chapter will only present elements within the model that differ from those reviewed in Chapter III.

2. Model Development

a. Costs

The following cost components of the expected annual total variable costs change as a result of incorporating both shelf-life extension and CA material considerations.

(1) Purchase Costs. The purchase costs formula must be modified by adjusting annual demand. Expected disposals due to material shelf-life expiration must be added while subtracting both material expected to be extended and expected CA material receipts. This modification is shown as follows in the formula for expected annual purchase costs:

$$C_P[R + X_d - X_e - Y(1 - d_r)].$$

(2) Order Costs. The annual demand used in calculating expected order costs must be adjusted in the same manner discussed above. The following formula then applies for the expected annual order costs.:

$$A[\frac{[R + X_d - X_e - Y(1 - d_r]}{Q}].$$

(3) Backorder Costs. Again, annual demand must be adjusted as before to arrive at the expected annual backorder costs. The result is shown below:

$$C_b\left[\frac{[R + X_d - X_e - Y(1 - d_r)}{Q}\right] [E(LTD > ROP)].$$

(4) Disposal Costs. Expected annual disposal costs must include material disposed of because it is returned, but not reusable and because its shelf-life is expired and it cannot be extended. It may not be extended either because it fails extension testing or because it is not considered economically feasible to test it for possible extension. The expected annual disposal costs are then:

$$C_D(Yd_r + X_d).$$

b. *The Total Costs Model*

The new expected Total Annual Variable Costs function is then determined by summing the formulas for all of the relevant cost components.

$$TVC = C_P(R + X_d - X_e - Y(1 - d_r) + A\left[\frac{[R + X_d - X_e - Y(1 - d_r)]}{Q}\right]$$
$$+ IC_P\left[\frac{(Q + X_e)}{2} + SS\right] + C_b\left[\frac{[R + X_d - X_e - Y(1 - d_r)]}{Q}\right][E(LTD > ROP)]$$
$$+ C_D(Yd_r + X_d) + C_t(N_t).$$

Next, the Economic Order Quantity equation is found by taking the first derivative of the TVC equation with respect to Q and setting it equal to zero. The following equation results:

$$Q = \sqrt{\frac{2[R + X_d - X_e - Y(1 - d_r)][A + C_b E(LTD > ROP)]}{IC_P}}.$$

The equation for the risk of stockout is revised to include the new backorder cost formula. The new equation is shown below:

$$P[LTD > ROP] = \frac{QIC_P}{C_b(R + X_d - X_e - Y(1 - d_r))}.$$

The equation to determine the implied backorder cost is then obtained by rearranging the variables as follows:

$$C_b = \frac{QIC_P}{P[LTD > ROP][R + X_d - X_e - Y(1 - d_r)]}.$$

With these revised formulas, optimal Q and ROP values can be obtained through the same iterative process described in Chapter III. An example is presented in Subsection D of this chapter.

C. THE MODIFIED SILVER MODEL WITH SHELF-LIFE ENHANCEMENTS

1. Background

As noted in Chapter III, Robillard's (1994) Modified Silver model is a periodic review model which seeks the least total variable costs per unit time while allowing for stochastic lead times. This model does not account for the disposal or extension costs that are routine in HAZMAT management. Piburn and Smith incorporated disposal costs into the Mod-Silver model. The model presented below incorporates both disposal and extension related costs into the Mod-Silver model.

2. Model Development

a. Costs

The cost formulas that change or result from incorporating shelf-life factors are holding costs, disposal costs, and extension costs. Changes to these costs are discussed in the following subsections.

(1) Holding Costs. The holding cost is calculated by adjusting the expected period demands. The expected disposals due to shelf-life expiration, X_{di}, must be added to a period's expected demand. The expected number of extensions for the period, X_{ei}, as well as the expected CA material receipts, must be subtracted from a period's expected demand. The resulting formula is:

$$IC_P[\sum_{i=1}^{T} (i - 1) |d_i^*|],$$

where,

$$d_i^* = d_i + X_{d_i} - X_{e_i} - w_{i-1}(1 - d_r).$$

(2) Disposal Costs. The disposal costs must incorporate disposals from all sources. This formula includes disposals from returned material that is not reusable and from expired material that either did not pass an extension test or did not meet the requisite criteria of the economic feasibility test to qualify for extension testing. The formula for disposal costs is therefore:

$$C_D[\sum_{i=1}^{T} (w_{i-1})d_r + X_{d_i}].$$

(3) Extension Costs. The extension costs are the actual cost incurred by testing the material to determine if the material can be extended and the cost to relabel the material multiplied by the number of tests conducted during the order cycle. Extension costs appear in Murray's model, but not in the Piburn and Smith version of the Mod-Silver model. Extension costs are added to this model by using the following formula from Murray (1995):

$$C_t(N_T).$$

Here $N_{\bar{T}}$ is the number of times in the order cycle that the material is tested for possible extension. This is implicitly a factor of the feasibility of the test based on the cost of the extension test(s) as compared to the replacement cost and disposal cost.

(4) Adjusted TRCUT(T) Equation. The resulting adjusted TRCUT(T) formula, with the additional cost factors incorporated, is presented below:

$$\frac{IC_P[\sum_{i=1}^{T}(i-1)|d_i^*|] + C_D[\sum_{i=1}^{T}(w_{i-1})d_r + X_{d_i}] + C_b[\sum_{i=1}^{L+T} d_i^* > (X2 + b\sigma_{X2}) + (X3 + k_r\sigma_{X3})] + C_t(}{T}$$

b. *The Total Costs Model*

(1) Order Interval. The optimal Order Interval (T) is considered to be that T which provides the global minimum for the TRCUT formula over the forecast horizon. By following the same logic pursued by Robillard (1994) to determine an approximate value for optimal T; namely, Q=RT from the EOQ model. Therefore, substitution of the revised formula for the optimal order quantity (Q), found in Subsection B of this chapter, into

$$T \simeq \frac{Q}{R},$$

results in the following equation for approximate optimal T (in years):

$$T \simeq \sqrt{\frac{2[A + C_b E(LTD > ROP)]}{IC_P[R + X_d - X_e - Y(1 - d_r)]}}.$$

In use in the Mod-Silver model it is then converted to the number of time periods and rounded to the nearest integer.

D. MODEL EXAMPLES

The following examples illustrate the use of the models presented in this chapter and are then later used in computer simulations to evaluate each model's performance.

1. Enhanced Economic Order Quantity Model Example

The following information is assumed:

R	= Normal (200,15) units per year
A	= \$53.00 per order
I	= 21% per unit per year
$\mathbf{C_P}$	= \$80 per unit
$\mathbf{C_D}$	= \$5 per unit
$\mathbf{X_d}$	= 10 units per year (5% of R)
$\mathbf{X_e}$	= 40 units per year (20% of R)
L	= 1 month
$\mathbf{D_{LT}}$	= $[R+X_d-X_e-Y(1-d_r)]$ (L/12 months) = 12.5 units
LTD	= Normal (12.5, 4) units
$\mathbf{\sigma_{DLT}}$	= 4 units
Y	= 20 units (2% of R)
$\mathbf{d_r}$	= 0.4 units (2% of Y)
Service Level	= 99%

a. Step 1. Determine the Initial Order Quantity (Q)

The initial Q value must be determined as an opening value in the iterative process. Using the formula for optimal Q without the backorder cost factor results in the following:

$$\textit{Initial } Q = \sqrt{\frac{2[R + X_d - X_e - Y(1 - d_r)][A]}{IC_P}};$$

$$\textit{Initial } Q = \sqrt{\frac{2[200 + 10 - 40 - 20(1 - 0.02)]53}{(0.21)(80)}} = 30.81.$$

b. *Step 2. Determine E(LTD > ROP) and the Standard Normal Deviate (z)*

The initial Q value is used to find the expected value of lead time demand that exceeds the ROP.

$$E(LTD > ROP) = Q(1 - \textit{Service Level}) = 30.81(1 - 0.99) = 0.3081.$$

This value is set equal to the following equation to determine the value of z:

$$E(LTD > ROP) = \sigma_{D_{LT}}(f(z) - zP(LTD > ROP)) = 0.3081;$$

where f(z) is the value of the density function of the standardized Normal distribution.

Table 4.1 shows possible z values with the related f(z), P(LTD > ROP), and E(LTD > ROP). The appropriate z value is found by finding the closest E(LTD > ROP) value to that value determined from the service level equation. In this case the appropriate z value is 1.04. Note that it is not the exact z value but is close enough to get the iterative process started.

z	f(z)	P(LTD > ROP)	E(LTD > ROP)
0.00	0.3989	0.5000	1.5956
1.00	0.2420	0.1587	0.3332
1.10	0.2179	0.1357	0.2745
1.01	0.2396	0.1562	0.3274
1.02	0.2371	0.1539	0.3205
1.03	0.2347	0.1515	0.3146
1.04	0.2323	0.1492	0.3085
1.05	0.2299	0.1469	0.3026

Table 4.1. Successive z values used in the iterative process for optimal Q and ROP.

c. ***Step 3. Calculate Implied Backorder Cost***

Once the z value is selected from the Table 4.1, the P(LTD > ROP) and the E(LTD > ROP) can be read directly from the table. With this information, the unit backorder cost, C_b, and a revised order quantity can be determined by using the equations developed earlier. C_b is found as shown below:

$$C_b = \frac{QIC_P}{P[LTD > ROP][R + X_d - X_e - Y(1 - d_r)]};$$

$$C_b = \frac{30.76 \ x \ 0.21 \ x \ 80}{0.1492[200 + 10 - 40 - 20(1 - 0.02)]} = 23.09.$$

d. ***Step 4. Determine a New Value for Q***

Once the backorder cost is determined, it is used in the EOQ equation to find a new value for Q, as shown below:

$$Q = \sqrt{\frac{2[R + X_d - X_e - Y(1 - d_r)][A + C_b E(LTD > ROP)]}{IC_P}};$$

$$Q = \sqrt{\frac{2[200 + 10 - 40 - 20(1 - 0.02)][53 + 23.09(0.3085)]}{0.21 \ x \ 80}} = 32.77.$$

The new Q value becomes the starting point for the next iteration. The iterative process continues until the Q values converge. The Q values in this example converge after two more iterations, with a final Q value of 33 units. The associated Normal deviate is z =1.01.

e. ***Step 5. Determine the ROP Value***

After the Q values converge then the associated ROP value can be calculated:

$$ROP = D_{LT} + z\sigma_{D_{LT}} = 12.5 + 1.01(4) = 16.54 \approx 17.$$

The reorder point in this example is 17 units.

2. Enhanced Modified Silver Model Example

This example assumes the same data as the previous example. In addition, it assumes the following:

Period Length	= 1 month
$\mathbf{t_0}$	= Start of Period 1
b	= 0.50

IP (at t_0)	= 15 units
σ_{X1}	= 8.55 units
σ_{X2}	= 7.01 units
σ_{X3}	= 9.63 units
k_r	= 2.33 (Service Level is 99%)

The period demand data was generated by using the SIMAN statistical software package. The distribution used was the same as for R in this example, Normal (200,15). The statistical program then generated random demand numbers which were used to determine d_i for each period shown in Table 4.2. A period's length is one month. This data was adjusted by the same percentages used in the continuous review example to get the values of X_{di}, X_{ei}, Y (for w_{i-1}), and d_r shown in the EOQ example to determine d_i^*. The latter's formula was given in Section C.2.

Period	d_i	X_{di}	X_{ei}	$w_{i-1}(1-d_r)$	d_i^*
1	11	0.55	2.2	1.078	8.3
2	15	0.75	3.0	1.470	11.3
3	8	0.40	1.6	0.784	6.0
4	20	1.00	4.0	1.960	15.0
5	16	0.80	3.2	1.570	12.0
6	4	0.20	0.8	0.392	3.0
7	11	0.55	2.2	1.078	8.3
8	9	0.45	1.8	0.882	6.8
9	11	0.55	2.2	1.078	8.3
10	16	0.80	3.2	1.570	12.0
11	18	0.90	3.6	1.764	13.5
12	15	0.75	3.0	1.470	11.3

Table 4.2. Sample Demand Data.

a. Step 1. Determine the Optimal Order Interval (T)

The example information provided allows us to calculate the approximate length of the order interval by using the following equation derived in the preceding section:

$$T \doteq \sqrt{\frac{2[A + C_b E(LTD > ROP)]}{IC_P[R + X_d - X_e - Y(1 - d_r)]}};$$

$$T \doteq \sqrt{\frac{2[53 + 23.5(0.3274)]}{0.21 \, x \, 80[200 + 10 - 40 - 20(1 - 0.02)]}} = 0.2195 \; years.$$

This value needs to then be converted into integer numbers of months since one month is a period's length:

0.2195 years x 12 = 2.63 ≈ 3 months.

b. Solve for the Expected Demand Variables X1, X2, and X3

From the demand data provided X1, X2, and X3 can be calculated by taking the demand, d_i^*, as adjusted in Table 4.2, summing it for the periods concerned, and rounding up to an integer. In this case the interval from t_0 (start of period 1) to L+1 (end of period 3) is 20 units, which represents X1. The interval from t_0 (start of period 1) to T-1 (end of period 3) is 20 units, which represents X2. The last interval, from T-1 (end of period 3) to T+L (end of period 5) is 21 units, which represents X3. X1, X2, and X3 are shown on the next page in Figure 4.1.

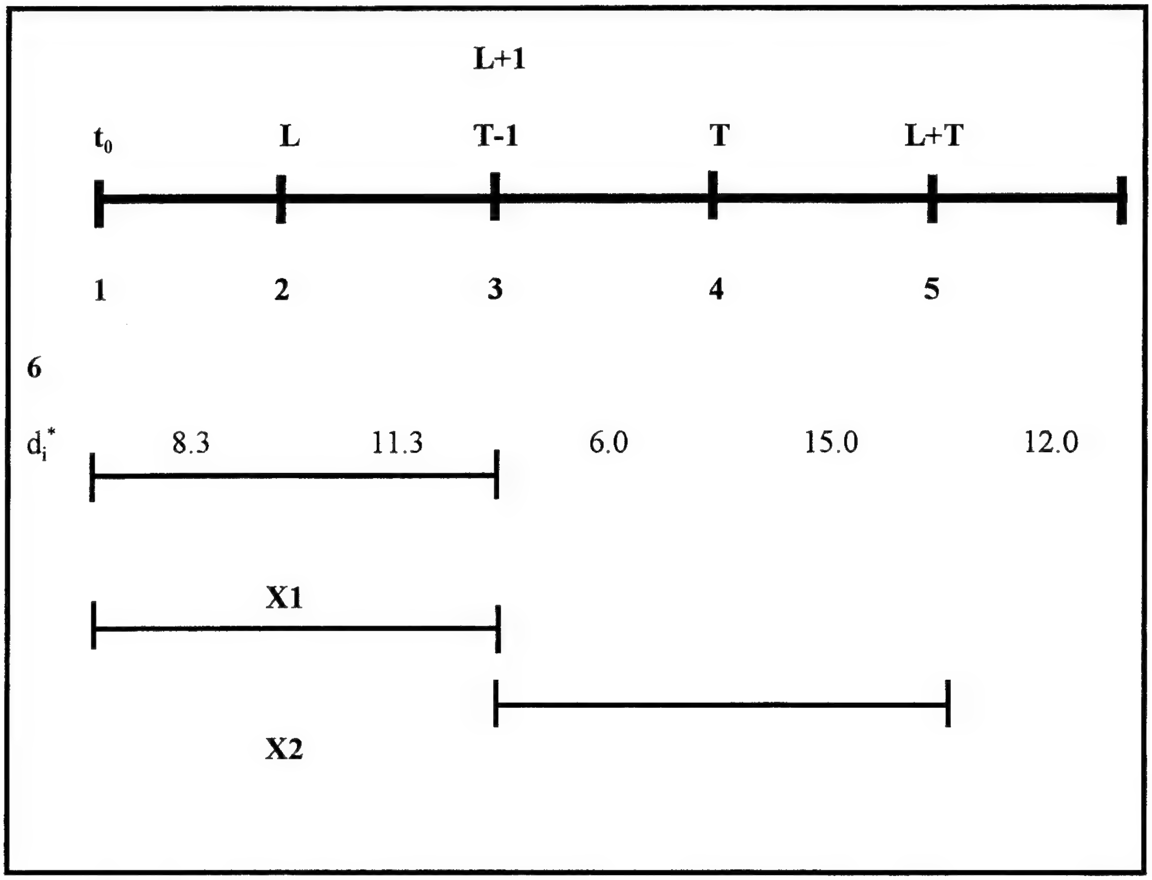

Figure 4.1. X1, X2, and X3.

c. ***Step 3. Solve for the Standard Deviations of X1, X2, and X3***

The standard deviations for X1, X3, and X3 are given in this example. In actual practice they would be calculated using the appropriate formulas discussed in Chapter III.

d. ***Step 4. Determine if a Reorder is Required.***

An order is required when the actual safety factor, k_a, is less than or equal to the required safety factor, k_r. The value of k_a for this example at t_0 is calculated as follows:

$$k_a = \frac{IP - X1}{\sigma_{X1}} = \frac{15-20}{8.55} = -0.5848.$$

Since,

$$k_a = -0.5848 < 2.33 = k_r,$$

a reorder is required at t_0.

e. Step 5. Determine How Much to Order (Q)

The order quantity is determined by using the order quantity formula for the situation where T>1. This was presented in Chapter III as:

$$Q = (X2 + b\sigma_{X2}) + (X3 + k_r\sigma_{X3}) - IP$$

So,

$$Q = [20 + (0.5)(7.01)] + [21 + (2.33)(9.63)] - 15 = 66.94 \approx 65 \textit{ units.}$$

Therefore, the order quantity at t_0 is 65 units.

3. Model Comparison

A comparison of the two models can be made by looking at their respective order quantities, reorder points, and order intervals averaged over many time periods. This comparison is of value in understanding the differences in the two models. The respective values are shown below:

Model	Q (units)	ROP (units)	T (months)
EOQ	33	17	1.98
Mod-Silver	41	20	3

Note that the T for the EOQ model and the Q and ROP for the Mod-Silver model are average values since these values vary over time. They were obtained from simulating both models for four years of demands.

The significant difference between the two models is the constraint placed by periodic review. The differences between the T values illustrates the impact of the constraint. The EOQ model, being a continuous review model, actually orders whenever

the reorder point is reached and the time between orders is a random variable with the average of 1.98 shown above. If the periodic review T were reduced to two months, the values of its Q (average order quantity) and reorder point would be closer to that of the EOQ but would still be larger due to the constraint.

E. DETERMINING IF MATERIAL SHOULD BE TESTED FOR EXTENSION

1. Test Formula Modification for Use with the Modified Silver Model

A decision of whether or not material should be tested for extension may be based on the replacement purchase, extension, and disposal costs of the extended material as compared to the testing costs for extension approval. Testing material for extension often results in avoiding pollution, disposal, and replacement costs. When the costs of replacement and disposal exceed the cost to test an item or a group of like items for extension, then the it should be tested for extension. If this condition is not met, the item or group of items should be disposed of and replaced with "A" condition material. A marginal analysis, like the one used by Murray (1995), can be used to determine the economic feasibility of extension testing for both models presented in this chapter.

The formula developed by Murray for use with the EOQ model can also be used in conjunction with the Mod-Silver model. The only adjustment that must be made is to change the per unit order cost segment of the inequality Murray used. That inequality was

$$[C_D + \frac{A}{Q} + C_P] \geq \frac{C_t}{X_e}.$$

It is still applicable for the EOQ model developed in this chapter. For the periodic review model it can be adjusted by using the following approximation:

$$\frac{A}{Q} \approx \frac{A}{[R + X_d - X_e - Y(1 - d_r)]T},$$

where T has units of years. If T has units of months then

$$\frac{A}{Q} \approx \frac{12A}{[R + X_d - X_e - Y(1 - d_r)]T}.$$

Using A/Q instead of the approximation will not work in the Mod-Silver model because Q is constantly changing.

Substitution of the approximation into Murray's inequality gives the following shelf-life extension test inequality:

$$(C_D + \frac{12A}{[R + X_d - X_e - Y(1 - d_r)]T} + C_P) \geq \frac{C_t}{X_e}.$$

2. Example

The parameters used in Section D of this chapter will be used in the formulas above to demonstrate the use of the feasibility tests for both local and off station testing.

Q (EOQ model)	= 33
$\mathbf{X_d}$	= 10
$\mathbf{X_e}$	= 40
$\mathbf{Y(1\text{-}d_r)}$	= 20
A	= $53.00 per order
$\mathbf{C_t}$ **- Local**[1]	= $2.40 per test

[1] The local extension costs were selected based on the assumed cost of the worker performing the test and the time frame required to complete both the test and the material relabeling; $12.00 per hour ($0.20 per minute) multiplied by 7 minutes for local testing plus 5 minutes for relabeling. (Lezniewicz, 1995) This is the same local extension cost value used in the computer simulations used to evaluate the performance of these inventory models.

C_t - Off Station[2]	= \$300.00 per test
C_P	= \$80.00 per unit
C_D	= \$5.00 per unit
R	= Normal (200,15) units
T (Mod-Silver model)	= 3 months

Evaluated the EOQ model for local extension testing:

$$[C_D + \frac{A}{Q} + C_P] \geq \frac{C_t}{X_e}$$

$$[5 + \frac{53}{33} + 80] \geq \frac{2.4}{40}$$

$$86.61 \geq 0.06.$$

Therefore, the local extension test should always be performed for the EOQ model when the other costs are as shown. For the Mod-Silver model, substitution of the cost and demand data gives:

$$(C_D + \frac{12A}{[R + X_d - X_e - Y(1 - d_r)]T} + C_P) \geq \frac{C_t}{X_e}$$

$$[5 + \frac{12 x 53}{[200 + 10 - 40 - 20]3} + 80] \geq \frac{2.4}{40}$$

$$86.41 \geq 0.06.$$

Thus, the local extension test should always be conducted for the Mod-Silver model for

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[2] The off station extension costs were selected based on the same material relabeling cost used in the local extension costs plus the \$300.00 per test approximated by Murray (1995). This is the same off station extension cost value used in the computer simulations used to evaluate the performance of these inventory models. The HAZMINCEN at Point Mugu indicated that all items were tested locally. (Lezniewicz, 1995) Based on this information the computer simulation is set to test 95% of all material locally.

this example data.

Next an evaluation of off-station extension testing should be made. For the EOQ model its inequality gives:

$$[C_D + \frac{A}{Q} + C_P] \geq \frac{C_t}{X_e}$$

$$[5 + \frac{53}{33} + 80] \geq \frac{301}{40}$$

$$86.61 \geq 7.53.$$

so off-station testing is economically justified. For the Mod-Silver model the test shows similar results:

$$(C_D + \frac{12A}{[R + X_d - X_e - Y(1 - d_r)]T} = C_P) \geq \frac{C_t}{X_e}$$

$$[5 + \frac{12 \; x \; 53}{[200 + 10 - 40 - 20]3} + 80] \geq \frac{301}{40}$$

$$86.41 \geq 7.53.$$

For this example, the off-station test would not be justified if it cost more than \$3,465 for either model.

V. SIMULATION MODELING

A. DEVELOPING A SIMULATION MODEL

Simulation can be defined as the process of designing a model of a real system and conducting experiments with the model to gain an understanding of the behavior of the system. These experiments can also aid in the evaluation of various proposed strategies for the operation of the system. (Pegden, Shannon, and Sadowski, 1995) These alternative strategies can be evaluated without having to actually implement them in the operation of the system through the use of simulation modeling. Simulation modeling also facilitates decision making based on a systems approach. Each subsystem may be modeled and evaluated without losing sight of the potential impact on the overall system.

The inventory models developed in Chapters III and IV have not been evaluated for use in HAZMAT management due to an absence of adequate demand data. These inventory models have the potential to reduce government costs in HAZMAT management, but must first be evaluated with regard to its expected impact on the relevant material management costs. This chapter describes a simulation model that will be used as an evaluation tool for the inventory models proposed in Chapters IV.

B. SIMULATION MODEL DESIGN AND CONCEPTS

The simulation model developed in support of this research uses the educational version of the SIMAN simulation language, developed by C. Dennis Pegden. SIMAN (<u>SIM</u>ulation <u>AN</u>alysis) is a commercially available general-purpose language that uses a logical modeling framework to aid in programming. (Pegden, Shannon, and Sadowski, 1995) The simulation problem is segmented into a "model" frame and an "experiment" frame. The model describes the physical elements of a system, such as workers, material flow, and storage points, and their logical interrelationships. The experiment frame outlines the experimental conditions under which the model is to run and defines the type of and content of the output for the purpose of evaluating the system's performance. The

major limitation of the educational version of the SIMAN software impacting this research was an upper limit of 150 entities allowed in the system at any given time. Each active action and each unit of material tracked in the system constituted an entity. The level of demand was therefore limited because as demand increased the level of on-hand inventory also increased; each unit of inventory equates to an entity in the system. The system terminates without completing the full simulation if the maximum number of entities is exceeded.

Designing a useful decision support model requires that simplicity and precision be appropriately balanced. Simplicity can help in understanding the model's generalizations, but can result in some loss of accuracy because some details deemed to have little or no impact with respect to the program's objectives are omitted. The balance must allow the model to behave sufficiently like the real system to allow decision makers to draw valid conclusions from its use. Highly complex models which attempt to simulate every detail, including incidental aspects of the real system, are more likely to contain undetected bugs that introduce unacceptable errors. For this reason the model to be described here intentionally tends toward minimizing complexity.

1. Model Frame

The purpose of the simulation model is to create a variety of material demands to aid in the understanding and evaluation of the proposed inventory management models. This required modeling three primary subsystems of the HAZMINCENs; namely, material replenishment, material issue, and shelf-life extension. Specifically the components of the system include:

- Material replenishment review procedures.
- Returned (CA) material processing procedures.
- Material issue procedures.
- Shelf-life testing and extension procedures.

The mechanics of disposal and material backorder procedures were excluded from

the model since their costs could be evaluated based on noting occurrences without detailing the procedures.

2. Selection of Model Type

A dynamic discrete-event simulation model was selected because it provides the ability to look at the state of the system at selected time intervals. (Law and Kelton, 1991) This simulation also modeled a non-terminating steady state system. As a consequence, a warm-up period could be specified to ensure ongoing steady-state conditions exist prior to data collection.

3. Assumptions

The assumptions are built in the framework of the model component of the program. The model, then, can only make "decisions" that are expressly present in the logic. The key assumptions are outlined in the following sections which describe the model. Key assumptions are:

- The default priority rule for issuing of material is the shortest remaining shelf-life.
- While material is undergoing test for extension it is unavailable for issue and is not included in the inventory position.
- Customers are offered CA material first. If they accept, their request is filled with CA material. If CA material is not available in sufficient quantities, "A" condition material is used to fill the remainder of the customer's order. If the customer insists on "A" condition material, then the order is filled as requested. Any part of an order not satisfied by on-hand "A" condition material is noted as a backorder and the backorder cost is calculated.
- Both CA and "A" condition material are considered as on-hand material when considering stock replenishment.

4. Input Variables

The simulation model of a system requires random variable inputs to be defined by a probability distribution with estimates of its appropriate parameters. This underlying distribution generates random variables during the simulation run. Two basic methods have been suggested to choose the parameters and their associated distributions (Pegden, Shannon, and Sadowski, 1995):

- Collect data from an existing source. Using standard techniques of statistical inference a distribution is selected which "fits" the data.
- Use a heuristic approach for choosing a distribution in the absence of data along with expert opinion to estimate input variables.

The heuristic approach was used to provide input variables for the simulation model. The Point Mugu HAZMINCEN was able to provide expert opinion on either average or range of specific processing times to be incorporated into the simulation model. (Lezniewicz, 1995) This information coupled with the authors' knowledge and experience in supply system operations provided the information necessary to use the heuristic approach for choosing reasonable parameters and distributions for processing times and demand quantity and frequency distributions.

5. Output Variables

Most non-terminating systems must go through a transient phase prior to reaching steady-state behavior for the system. This characteristic requires some adjustment to increase the reliability of the output. (Pegden, Shannon, and Sadowski, 1995) The three most promising approaches to reducing the initial transient bias are:

- Reduce the transient phase by selecting the appropriate starting conditions for the run.
- Discard data during the initial portion of the simulation, avoiding biased observations from the transient phase.
- Run the simulation long enough so that any data collected during the

transient phase will be dominated by data collected during the steady-state phase.

The use of discarded data during an initial warm-up period equivalent to twice the average lead time was selected as a means to reduce the initial transient bias in our simulation experiment.

Output variables must be selected that are capable of measuring desired aspects of the system. These output variables are required in order to make inferences concerning the performance of the system. Although inventory management systems can be evaluated by a variety of indicators, this thesis focuses on the major variable cost factors in evaluating the system; the Expected Total Annual Variable Costs. Expected Total Annual Variable Costs include purchase, ordering, holding, shortage, disposal, and extension costs. This evaluation is presented in Chapter VI.

C. DESCRIBING THE MODEL COMPONENTS

The following subsections provide a detailed description of the components of the HAZMAT inventory management system included in the model. The description defines the system and its boundaries. It establishes the relevant constraints and the variables of the model. As mentioned earlier, the model is composed of three primary subsections. This subdivision aids in simplifying the model development.

1. Material Replenishment

The material replenishment process can be based on a continuous or periodic review management system. A simulation model was developed to replicate the replenishment models developed in Chapter IV. Each version of the simulation model contains the appropriate formula for determining the order quantity for a specified inventory management model. Continuous review inventory management models trigger a reorder review based on the occurrence of a specified condition, inventory position is at or below the reorder point. Periodic review models conduct reviews at the specified order interval defined by the inventory management system and then determine whether an order

should be placed and if so, how much should be ordered based on the current inventory position.

As mentioned above, the lead time distribution was established based on expert opinion provided by Point Mugu. It was established as being representable as a Normal distribution with a mean of one month and a standard deviation of 15 days. Upon receipt of a new batch of "A" condition material the simulation model assigns a shelf-life to each unit prior to sending the material to the on-hand inventory. Shelf-life is based on a uniform distribution having a range of from one to three months less than the maximum allowable shelf-life of the item. This range allows for the material's shelf-life to age during the lead time and any interim storage time at the wholesale inventory level. Specific estimates for all input variables used in the simulation are provided in Appendix B.

2. Material Issue

The material issue subsystem is dependent on two primary distributions. The first is the distribution for customer requisition frequency. The other distribution is for the quantity of each customer requisition. Both of these distributions were reviewed by using a sample from one year of demand data provided by FISC San Diego. (Roiz, 1995) No single distribution constituted a majority in either category through a best fit analysis conducted by using the SIMAN statistical analysis software. In the review of customer requisition frequency the distributions observed included Beta, Exponential, Gamma, Lognormal, Poisson, and Triangular with the Beta distribution occurring most frequently. Even though the Beta distribution occurred most frequently, other distributions occurred almost as frequently. Thus, an Exponential distribution was assumed for customer requisition frequency per year for convenience. The review of the quantity demand per requisition produced similar results. In this case the Lognormal distribution occurred most frequently with other frequencies appearing almost as often. However, a Normal distribution was assumed as an approximation to the Lognormal for customer quantity demanded per requisition because it is the distribution used in Navy replenishment models

for items with high mean demand; the mean demand in the example used was 200 units annually or 17 units monthly.

Once the customer has indicated a preference for CA or "A" condition material, the material is then issued from the on-hand inventory based on the smallest remaining shelf-life available. If the material on-hand is insufficient to satisfy the customer request, no issue is made and a backorder (shortage) is accounted for in the model's cost calculations. Both Point Mugu and San Diego indicated that backorders are treated as special orders. A special order cost is not readily available and is assumed to be equivalent to the backorder cost. The special order material is turned over to the customer upon receipt, without ever being taken into inventory.

The model assumes customers will return the empty containers or any unused material within one week. The HAZMINCENs track issued material until it is disposed of or returned as CA material. CA material is tested for reusability upon return. This testing is conducted by the same personnel who return the material to storage and takes an average of only seven minutes. Therefore it is considered to be included in the holding cost rate. If the returned material is deemed reusable, it is considered CA and sent to the holding area. If it is not reusable, a disposal cost is accounted for in the model's cost calculations. Empty containers are disposed of when returned, but the cost is not counted as a relevant inventory cost for our purpose.

3. Shelf-life Extension

Each month the simulation model conducts a review of on-hand material to determine if the shelf-life of any material has expired. If any expired material is found in the on-hand inventory it is removed. The expired material is classified as Type II (extendable after testing) and, therefore, it is reviewed for extension.

Both simulation models first conduct a feasibility test to determine whether it is more economical to dispose of and replace the material or to test it for extension. The simulation replicates the feasibility test assuming the testing costs discussed in Chapter IV

for both local and off station testing. If it is disposed of, the disposal cost is the product of the item's weight in pounds multiplied by the disposal cost per pound. If the material is tested for extension and deemed extendable, which is assumed to occur 80 percent of the time, its shelf-life is extended for six months, the extension cost is calculated and it is returned to the on-hand inventory. If it is not extendable the disposal cost is calculated. The shelf-life of items typically varies from three months to five years. A six month shelf-life extension period was selected so the impact of material shelf-life expiration could be effectively evaluated in the test period of four years. The effect of a longer shelf-life is tested during the sensitivity analysis discussed in Section E of this chapter.

D. RUNNING THE SIMULATION MODEL

Because executing the model is somewhat complex, the three key steps in the process are summarized in Figure 5.1. The first step sets the conditions under which the model is run. In this step the inventory replenishment model parameters, shelf-life length, cost factors, customer demand distributions, returned material distributions, and material disposal distributions are set. The next step creates customer demands, issues material, replenishes material, conducts shelf-life reviews, disposes of material, and accumulates relevant costs. The final step summarizes the cost data for use in evaluating system performance.

Model Initiation

Set inventory replenishment model parameters.
Set shelf-life length probability distribution parameters.
Set cost factors.
Set customer demand frequency and quantity probability distribution parameters.
Set returned material probability distribution parameters.
Set material disposal probability distribution parameters for returned material and shelf-life expirations.

↓

Model Execution

Create customer demands based on the distribution parameters.
Issue material.
Test returned material.
Replenish material.
Conduct shelf-life review.
Dispose of material.
Accumulate relevant costs.

↓

Model Output

Cost data summaries and statistics are displayed for use in evaluating system performance.

Figure 5.1. SIMAN Simulation Model Program Flow

E. HAZMINCEN MATERIAL MANAGEMENT OPERATIONS

1. Defining the Conditions for the Simulation

Each simulation was designed to reflect management of a single line item of stock. A sample line item was constructed for use in testing the system. This item provided basic information used to generate comparable input to the simulation from both proposed inventory models.

Parameters for the respective replenishment models were determined and tested, first by using the same assumptions that had been used in the inventory models to calculate the order quantity, reorder point, and order interval presented at in Chapter IV. The scenario provided ideal conditions and was used as a baseline for comparison against the results obtained when a parameter was varied..

Sensitivity analyses were conducted by making changes to certain parameter values used in the basic scenario to test each inventory model's performance under less than ideal conditions; namely, closer to reality. The following changes were made to reflect a more realistic situation. They were made one at a time, resetting the parameters to their original values conditions prior to changing the next parameter's value.

(1) Quantity of material returned increased from 10% to 20%;

(2) Shelf-life changed from six months with an equivalent length of extension, to twelve months with an equivalent length of extension.

(3) Percentage of customers willing to accept CA material decreased from 75% to 50%;

(4) Percentage of material that fails test for extension increased from 20% to 40%.

By changing only one parameter during each run, the results of each can be more easily compared to the basic model to determine the impact of the change.

The simulation was set for a warm-up time equivalent to two months, followed by four replications equivalent to one year each. The warm-up period allowed time for stock

to be ordered, received, and placed in the storeroom for issue, thereby avoiding artificially inflated backorder costs. The system was not reinitialized after each replication. Thus, the non-terminating system in a steady-state condition could be continued through each replication without reverting to additional warm-up periods.

2. Running the Simulation

The simulation was run under the "identical conditions" (i.e., original set of parameter values) with the exception of the single change in each scenario for each inventory management model evaluated. A seed value was set to ensure the random number stream was constant for each version of the model making the results more comparable. Data collection began at the end of the warm-up period. At this point material of varying shelf-life was available to satisfy customer requests. Portions of initial issues had also been returned, establishing a CA inventory available to satisfy customer demands. All cost data was gathered and cumulative costs were reported at the end of each replication.

The flowchart pictured in Figure 5.2 describes the processes contained in the simulation model. The material replenishment subdivision of the simulation model involves the submission of replenishment orders to the DLA Depot when the inventory position drops below the reorder point. The inventory on-hand is then increased as these replenishment orders are filled.

The material issue subdivision of the model is shown as CA and "A" condition material being issued to the customer based on the customer's preference for a particular category of material. When the customer returns any unused material it is tested for reusability. If it is reusable it is put back into the inventory as CA material, if not it is sent to disposal.

As the "A" condition material's shelf-life expires, it enters the shelf-life extension subdivision of the simulation model. Each item must be evaluated based on the costs involved to determine whether it should be tested for possible shelf-life extension at the

beginning of the process, as shown in Chapter IV. If it is economical to test the material for possible shelf-life extension, the material is then tested against established extension criteria locally if possible, or sent off station if necessary. If the material can be extended, it is relabeled and returned to the on-hand inventory; if not, it is sent to disposal. Any material that could not be economically tested for extension is also sent to disposal.

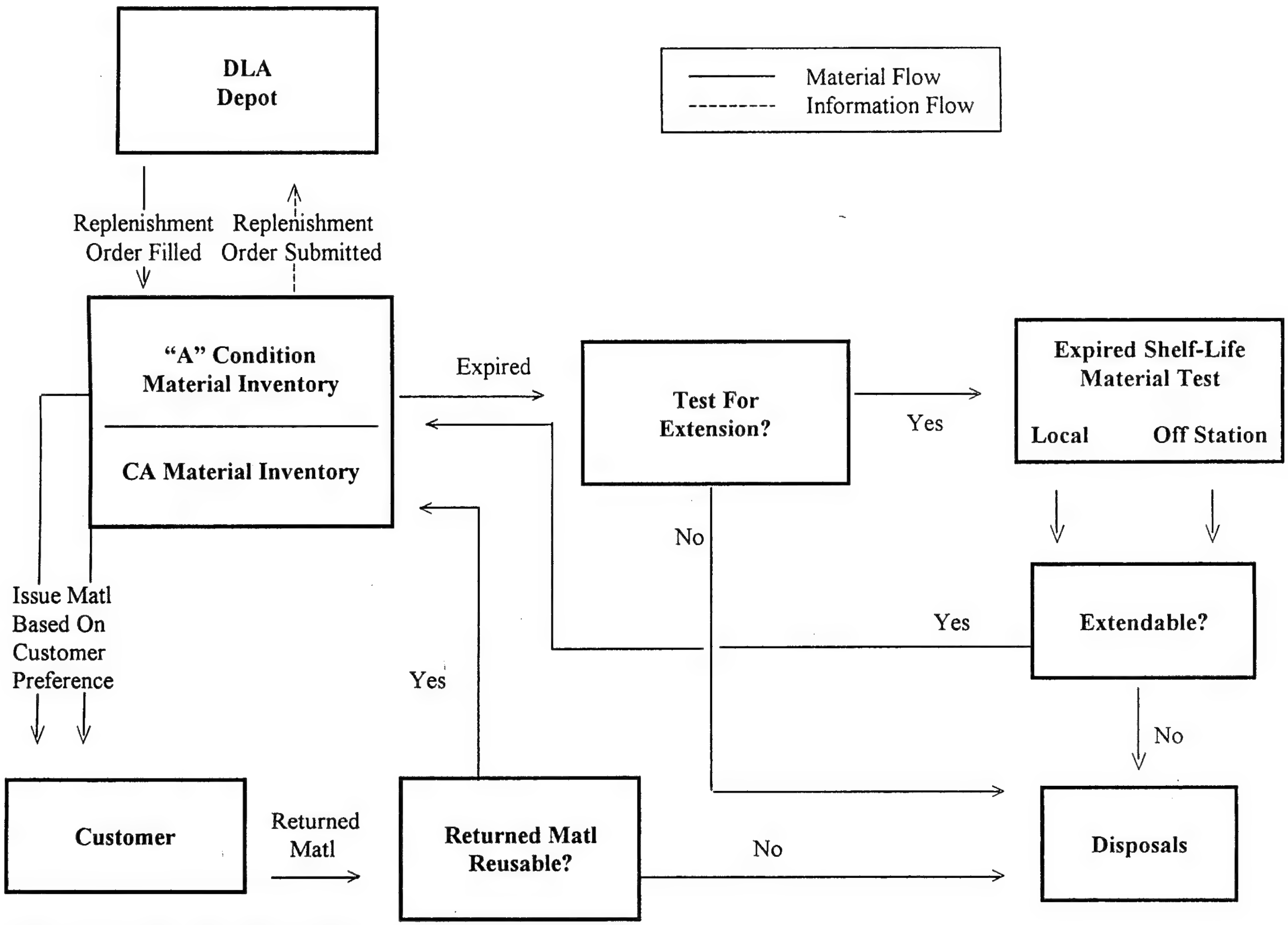

Figure 5.2. Simulation Flowchart.

F. SIMULATION RESULTS

The results of the simulations were evaluated and are presented in Chapter VI of this thesis. The total costs from the simulations are shown in Appendices E and F. A sample output report from the simulation model is presented along with copies of the model and experiment components in Appendices C and D for the EOQ and Mod-Silver models, respectively.

VI. COMPARATIVE ANALYSIS OF THE SIMULATION RESULTS

A. OVERVIEW

In this chapter we compare five simulation results of the two revised models presented in Chapter IV, the continuous review EOQ based model, called "EOQ" from now on, and the periodic review model based on Mod-Silver, hereafter called "MOD". As stated in the previous chapter, we ran the basic version of each followed by four changed scenarios for each model. The changes in each scenario are listed below:

(1) Quantity of material returned increased from 10% to 20%;

(2) Shelf-life changed from six months with a single equivalent length of extension, to twelve months with a single equivalent length of extension;

(3) Percentage of customers willing to accept CA material decreased from 75% to 50%;

(4) Percentage of material that fails test for extension increased from 20% to 40%.

Notice that none of the cost parameters are changed in any of the simulations. Cost parameters' values are not the immediate concern; performance under various demand situations is and has been since the work of Piburn and Smith. However, the TVC costs are contrasted to determine the best performing model based on the criteria of lowest costs. In addition, the components making up TVC (i.e., purchase costs, order costs, holding costs, backorder costs, disposal costs, and extension costs) are also compared. Any of these cost components that are significantly larger, smaller, do not seem to be logical, or do not make intuitive sense are also discussed.

The summary data generated by the simulations are found in Appendix E, Inventory Cost Summaries; and Appendix F, Simulation Results. Appendix E separately lists the TVCs and the individual inventory costs for the two models. Appendix F presents

each model's TVC and component costs for each of the five simulation runs. The values shown are the totals over all of each run. The TVCs and their component costs for each model run are both presented in tables and in bar charts. Purchase costs generated by the simulation were not charted since their percentage of TVC are no less than an 88% share for any simulation run.

B. SIMULATION RESULTS ANALYSIS

1. Total Variable Costs Comparison

Table 6.1 contains the total TVCs for the two models. The periodic model (MOD) outperforms the continuous model (EOQ) in the base case, plus the second and last scenarios. The MOD's TVCs for those runs are averaging almost $2,500 less than the EOQ model. However, this difference is less than 5% of the total. Furthermore, when the EOQ model has lower TVCs than the MOD, which occurs for the first and third scenarios, the difference averages $7,404 or approximately 13%. Thus, the model results are quite similar.

Why does the MOD generally do slightly better than the EOQ model for the basic and the second and fourth scenarios? It does so because it has lower values for the three major, dollar-wise, inventory costs; namely, purchasing, ordering, and holding costs.

Why does scenario #1's 10% increase in returned material (i.e., CA material) cause the MOD's relatively poorer performance (by approximately 14%)? Regarding the EOQ model, this increase in returned material results in the model purchasing less material because the extra CA material increased the model's inventory position (IP). When the model compares IP to ROP to determine whether or not it needs to reorder, the "CA-increase" delays the time when the IP drops below the reorder point. In the MOD's case, despite the increase in CA material, IP was never large enough to meet the model's service level over the L+T period so more material was ordered every time a review was made. The increase in CA was not large enough to result in a decrease of the total amount ordered below that of the EOQ over the simulated four years.

Why does scenario #3's decrease in the percent of customers willing to accept CA material increase the MOD's TVC? Even though this factor is not a parameter in any of the cost equations, decreasing the number of customer demands which can be filled by CA material has essentially the same effect as increasing the amount of CA returned in scenario #1.

Change/Model	EOQ	MOD
Basic Version	$62,094	$57,386
Scenario #1	$57,276	$63,219
Scenario #2	$59,223	$58,853
Scenario #3	$56,717	$65,581
Scenario #4	$64,116	$61,847

Table 6.1. Models' TVC Comparison.

2. Component Inventory Costs Analysis

This subsection reviews each of the cost components of TVC. The discussion focuses on any significantly large and small results, or patterns in the data. The data from the Basic Version is used for comparison.

a. Purchase Costs.

Scenario #1's increase in the quantity of material returned lowered the purchase costs for the EOQ model by $4,818 or a decrease of 8% when compared to the Basic Version. This effect was a consequence of more CA material being available to issue to the customers. Otherwise, additional new inventory would have had to be purchased to meet demand. The extra CA material obviously prevents or delays the stockout situation.

The EOQ model's purchase costs also decreased for the next two model scenarios. The decreases averaged $4,400. In the case of scenario #3 when only half the customers are willing to accept CA material, down from three-quarters of the customers, this behavior serves to cancel the benefits of the quantity of returned material. It then follows that the purchase costs should increase to fill demands with "A" condition material. It is not clear why they do not. They certainly do for the MOD.

As expected, MOD's purchase costs also increased for each model scenario. As with the EOQ model, the largest increase, $7,559, occurred for the third

scenario. It is not obvious why the longer shelf-life (an increase from six to twelve months) of scenario #2 drives up purchase costs slightly for the MOD. The EOQ result makes more intuitive sense (scenario #4). The increase in the number of failed extension tests, as expected, increases the purchase costs as more material is procured for replacement of the material disposed due to extension test failure. Increases in the quantity of material disposed and decreases in the quantity extended both drive up purchasing costs.

The above discussion concerning purchase costs is based on the results of a limited simulation run. Longer runs would have evened out the purchase costs since, in steady-state, each model's purchase costs would be the expected annual demand (multiplied by the item's unit price).

b. Order Costs.

The MOD version has lower ordering costs than the EOQ for each scenario. There were no significant changes (i.e., no greater than $106) for either model in order costs between the basic model and the four scenarios. The reason for the MOD results being better is that the order interval is longer and therefore fewer orders were placed under the MOD version for each year simulated.

c. Holding Costs.

Other than the first scenario, the simulation changes resulted in lower holding costs than the basic version for all the simulation runs of the EOQ model. And in that first scenario, holding costs only increased by $33. The decreases were also small for scenarios #2 through #4. The largest decrease for this model was $277 or 7% for scenario #4. For that case the scenario's increased number of extension test failures results in more disposals and therefore less inventory subject to the holding cost rate.

Holding costs for the MOD version increased except for the last scenario, where there is a slight decrease of $173. This was due to less expired material being returned to stock as a consequence of shelf-life extension and a greater delay in time to

replace this stock as compared to the EOQ model. The largest holding cost increase, \$355, occurred for scenario #2. Although the order frequency did not slow down, the doubling of the shelf-life increased the level of inventory subject to the holding cost rate.

d. Backorder Costs.

For the basic version and any scenario, the EOQ model always had greater backorder costs than the MOD. However, the difference was small, averaging \$263. The EOQ's backorder costs decreased an average of \$183 for each scenario. When considering the first two scenarios, this decrease in cost is reasonable. An increase in returned material (scenario #1) will allow the filling of more orders since more material is available for issue. The doubling of shelf-life (scenario #2) means material sits on the shelf longer and when it is extended, again doubles the length of time it is available.

The causes of the decreases in backorder costs for the last two scenarios is not clear. If half of the customers refuse to accept CA material (scenario #3), then there will be a greater demand on "A" condition material than normally expected. Consequently, one would expect a greater number of "not in stock" occurrences and, as a result, more backorders. If more material fails its extension test (scenario #4), then there is less material available, and following the same logic for scenario #3 above, more backorders results. However, the order costs went up so that helped prevent a larger number of backorders.

In the MOD, the increase in extension test failures of scenario #4 resulted in less extensions and therefore a greater number of backorders for each model. As discussed previously, a greater number of failed extension tests results in a greater number of disposals. An increase in the quantity disposed also raises backorder costs.

The MOD version has lower backorder costs than the EOQ model for each simulation runs. This is not expected since the EOQ model replenishes more frequently (T = 1.98 months) than the MOD version (T = 3 months) and hence, should have less backorders. However, the holding costs were higher for the MOD than the

EOQ, implying more inventory available to meet demands.

e. Disposal Costs.

Each model's disposal costs for all the simulations were very low. The highest total was $105 for the MOD version under scenario #4. This total represents 21 disposals (the disposal cost is $5 per unit) over a simulated four-year period. The disposal costs for each model were the same, $55, for the basic version. The MOD version had slightly higher disposal costs than the EOQ model for each scenario. There is a longer order interval under the MOD version, consequently the material sits on the shelf longer. The majority of disposals are due to expired shelf-life and the MOD version had more of these.

f. Extension Costs.

Extension costs did not follow a pattern. A comparison of the models for each scenario exhibits very different values (e.g., one cost is small and the other large), in four cases the EOQ model has the higher extension costs and in the remaining case, the MOD version is significantly higher. For example, The EOQ model had a high of $701 for the second scenario and the MOD had a much lower value of $99.

Scenario #1 increased each model's extension costs due to the greater quantity of material available for extension testing. The doubling of shelf-life of scenario #2 did not, as expected, reduce the extension costs of the EOQ model (i.e., $701 versus $383). Extension costs increased slightly, $6, for the MOD version for this scenario compared to the base case. This is still insignificant.

C. EVALUATION OF THE MODELS BASED ON THE SIMULATION RESULTS

We conclude that it is too early to say which of the two models is the better performing one. The criteria we used to evaluate the models are their associated TVCs over four simulated years of demand. The differences, for example, between the models for the basic version and scenarios #1 and #3 may in fact be due to having simulated the model behaviors for only four years.

If the only change in the basic model is to increase the percent of material returned (CA), the simulation results suggest the EOQ model is the better choice. The realistic goal is, however, to have as little CA material as possible. This saves on disposal costs and shelf-life extension costs.

Examining the individual inventory costs aids in understanding each model's behavior. A look at these costs can also help explain why a model's TVC under a simulation scenario changes from its base model. However, those results at this time are also really inconclusive since only four years were simulated.

The next chapter will present a summary of the thesis research, conclusions, and recommendations based on the simulation results.

VII. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A. SUMMARY

The emphasis of this thesis was to examine the effect of simulated demand for an item of HAZMAT on the performance of inventory models proposed for managing such items. Currently there is only one year of actual data on the demand of hazardous material at any HAZMINCEN. The evaluation of an appropriate inventory model requires at least two years of demand history and preferably more. Consequently, Monte Carlo simulation based on the year's worth of data was used to simulate demand over a four-year period. The software package used for developing the simulation model was SIMAN.

Chapter II was an overview of the Department of the Navy's current management of HAZMAT. It discussed the notion of shelf-life, and presented synopsis of previous studies related to HAZMAT inventory management. Chapter III reviewed three related recently developed HAZMAT inventory models: Piburn and Smith's EOQ, Murray's EOQ, and Robillard's Modified Silver Model that included Piburn and Smith's modifications. Chapter IV presents the details of extending the Murray EOQ model and Piburn and Smith's version of the Mod-Silver model to include shelf-life extensions. These models were the ones evaluated using simulation. Chapter V discussed simulation model design and concepts, and defined the conditions for the simulation of these models and the parameters for running it. Included were four scenarios designed to study the sensitivity of the models to demand related parameter changes and shelf-life extension effects. Finally, Chapter VI presented and discussed the results of the simulations.

B. CONCLUSIONS

1. Using Simulation Modeling

Modeling through the use of simulation furnishes an effective and sensible method to assist in the analysis of inventory models. Simulation saves time and money by allowing analysts, users and managers to consider various inventory techniques without the investment of time and fiscal resources in actual inventory. This technique also allows one to evaluate the models based on their replenishment policies and overall cost performance.

Simulation modeling does not provide the optimal solution to a problem. However, it is an extremely useful decision aid. Furthermore, the caliber of the model is based on its assumptions, its internal logic, and the validity of the input values. Therefore, the output data must be carefully scrutinized to see if the results are as expected for test cases, and any subsequent analysis must be conducted with caution. Simulation will not replace the wisdom, practical experience, and knowledge of the seasoned inventory manager or the schooled professional. However, it can assist in their decision processes.

2. The Best Performing Model?

The simulation results and subsequent analysis of the generated output data indicated neither model consistently produces lower TVCs when compared to the other model. In addition, the differences in the TVCs of the two models were really quite small.

3. Preferred Comprehensive HAZMAT Inventory Models

Due to the comprehensive nature of our two models, they are the preferred choice to be used in managing a HAZMINCEN. Our models were based on the recent work of Piburn and Smith, Murray, and Robillard. However, each of these had shortcomings. Piburn and Smith's continuous EOQ model did not consider disposal or extension costs. Their version of Robillard's periodic review model did not include an extension cost. And lastly, Murray's version of the EOQ model failed to account for customer returned material. The two models developed in this thesis are therefore the first ones to

incorporate all of the HAZMAT inventory cost components, including both a disposal cost and an extension cost.

C. RECOMMENDATIONS FOR FURTHER RESEARCH

Despite previous related theses, this field of study remains ripe for further research. We have five recommendations concerning this topic area.

1. Run Longer Simulations

Using the commercial version of the SIMAN software, longer simulation runs could be conducted for the proposed inventory models. Because of the closeness of the performance of the two models developed and analyzed in this thesis a longer run time seems appropriate to get better statistics. We recommend a period of at least simulated ten years. This length of time would provide more representative and comprehensive outputs that should allow for a more accurate assessment of the simulated TVC costs of each inventory model. If they continue to be close in value then the decision maker can select the one which is most appropriate for how they wish to manage the item inventories based on budget constraints.

2. HAZMINCENs should begin tracking the percent of issues returned, the quantity per return, and the rate of disposal

This information would assist in determining the probability distributions of material returns and forecasting the mean rate of material returns. The forecasting would help indicate how many customers are returning material and how much of the material is returned on average per customer. An accurate forecast of the level of returns is essential in selecting a model. In addition, the rate of disposal was assumed to be 2% in the models developed thus far. Its actual distribution is needed as well as a forecast of its mean rate.

3. Find the point where the percentage of returned material results in a lower TVC for the EOQ model

The impact of varying the rate of return of CA material which was begun using scenario #2, needs to be studied further. Subsequent simulations should be run which vary

it from zero to 100% to better understand its effect on both models.

4. Simulate HAZMAT Demand Databases

After several more years of demand data becomes available from HAZMINCENs (e.g., FISC San Diego and FISC Puget Sound) it should be run through the simulation to evaluate the two models proposed in this thesis.

5. Build a Spreadsheet to Allow Use of both the EOQ and Periodic Models

Using current commercial spreadsheet software package (e.g., Excel or Lotus 123), an interactive spreadsheet should be built for both models. This would, in essence, represent an expert system for an inventory manager. The inputs that would be needed in building this spreadsheet would be like those inputs found in Appendix B. This tool would be used to calculate the optimal reorder point, order interval (T), and order quantity, rather than base their values on so-called "professional judgment" of inventory managers. It should also provide calculated TVCs for any desired other values of the decision variables.

APPENDIX A. LIST OF ABBREVIATIONS AND ACRONYMS

CA	Cost Avoidance
CHRIMP	Consolidated Hazardous Material Reutilization and Inventory Management Program
DRMO	Defense Reutilization Management Office
EOQ	Economic Order Quantity
EPA	Environmental Protection Agency
FIFO	First-In, First-Out
FISC	Fleet and Industrial Supply Center
HAZMAT	Hazardous Material
HAZMATCEN	Hazardous Material Management Center
HAZMINCEN	Hazardous Material Minimization Center
HICS	Hazardous Inventory Control System
MAD	Mean Absolute Deviation
MILSPEC	Military Specification
MILSTD	Military Standard
NASNI	Naval Air Station North Island
NAVSUP	Naval Supply Systems Command
NAWS	Naval Air Weapon Station
NSN	National Stock Number
SIMAN	Simulation Analysis
TRCUT	Total Relevant Cost per Unit Time
TVC	Total Annual Variable Costs

APPENDIX B. INPUT VARIABLES

A. SIMULATION INPUT VARIABLES

1. Basic Scenario

Variable [3]	Value	Source
Order Cost	$53.00	1
Holding Cost Rate	21%	1
Extension On Site Test Cost	$1.40	3
Extension Off Station Test Cost	$300.00	1
Extension Labeling Cost	$1.00	3
Disposal Cost	$5.00	4
Backorder Cost	$23.50	5
Purchase Cost	$80.00	4
Expected Number of Extensions	40 (20% of Mean Annual Demand)	5
Disposals due to Shelf-Life Expiration	20% of Expirations	4
Safety Stock Coefficient	0.5	2
Required Safety Stock Factor	2.33 (99% Service Level)	2

[3] Source Codes:

1 Murray (1995)

2 Piburn and Smith (1994)

3 Point Mugu HAZMINCEN

4 Assumed

5 Calculated in Inventory Model (Chapter IV)

Document Preparation Time	Exponential - Mean of 5 minutes	3
Lead Time	Normal - Mean of 30 days, Standard Deviation of 15 days	3
Returned Material Test Time	Exponential - Mean of 7 minutes	3
Material Storage Time	Exponential - Mean of 20 minutes	3
On Site Extension Test Time	Exponential - Mean of 7 minutes	3
Off Station Extension Test Time	Uniform - Minimum of 1 week, Maximum of 3 weeks	4
Extension Labeling Time	Exponential - Mean of 5 minutes	3
Shelf-Life Review Frequency	1 month	4
Customer Material Holding Time	Exponential - Mean of 1 week	3
Initial Shelf-Life	Uniform - Minimum of 3 months, Maximum of 5 months	4
Extended Shelf-Life	6 months	4
Quantity Returned	10% of Issues	4
Customers willing to accept CA material	75% of requisitions	4
Returned Quantity Disposed	2% of Returns	4
Order Quantity	Normal - Mean of 4 units, Standard Deviation of 2.1 units	4
Customer Requisition Frequency	Exponential - Mean of 10,512 minutes	4
Order Quantity	33 units	5
Reorder Point	17 units	5
Order Interval	3 months	5
X1	20 units	5
X2	20 units	5
X3	21 units	5
σ_{X1}	8.55 units	5

σ_{X2}	7.01 units	5
σ_{X3}	9.63 units	5

2. Scenario One

The following change was made to the basic scenario:

Quantity Returned	20% of Issues	4

3. Scenario Two

The following changes was made to the basic scenario:

Initial Shelf-Life	Uniform - Minimum of 9 months, Maximum of 11 months	4
Extended Shelf-Life	12 months	4

4. Scenario Three

The following change was made to the basic scenario:

Customers willing to accept CA material	50%	4

5. Scenario Four

The following change was made to the basic scenario:

Disposals due to Shelf-Life Expiration	40% of Expirations	4

APPENDIX C. ECONOMIC ORDER QUANTITY (SIMAN PROGRAM)

A. PROGRAM MODEL FRAME

```
BEGIN;

;     Thesis HAZMINCEN EOQ Simulation, Stroh and Collins

;     General Information
;          Time is counted in units of minutes
;          The model runs only one line item at a time
;          Processing times are based on info provided by HAZMINCEN,
;            Point Mugu
;          Stochastic EOQ Model Version
;          Entering data are Qty and ReorderPt

;     Create orders

      CREATE: ED(11);                                    orders
      ASSIGN: qtyrqst=ED(12):                           !determine qty
rqstd
              Issqty=qtyrqst:                           !establish issue qty
              Demand=Demand+qtyrqst:NEXT(order);         record demand

;     Create holding cost calculation trigger

      CREATE,1,525599:525599:NEXT(hold);                 hold cost calc trig
```

```
;       Create reorder review action

rrev BRANCH,1:                                  !reorder required?
       IF,INVPOS.LE.ReorderPt, cont:            !yes
       ELSE,bye;                                no

;       Create shelf-life expiration review action

     CREATE,1,ED(14):ED(14);                    conduct SL
review
     SEARCH, hold1Q,1,NQ:TNOW.GE.SL;            ID expired matl
     BRANCH, 1:                                 !is queue empty?
       IF,J.EQ.0,bye:                           !yes
       ELSE, rem1;                              no
rem1REMOVE: J,hold1Q,ext;                       send to extend
submod
     DELAY:  0:NEXT(bye);                       dispose of rev
action


;       Issue Routine Submodel

order  BRANCH,1:                                !check inv on hand
         IF,CAINV.GE.qtyrqst,ca:                !issue ca matl
         IF,AINV.GE.qtyrqst,a:                  !issue a matl
         ELSE,rev1;                             conduct reorder
rev
```

```
doc   DUPLICATE:1,rrev;                        conduct reorder
rev
       QUEUE,  docQ;                           issue doc queue
       SEIZE:  clerk;                          get clerk
       DELAY:  ED(5);                          make issue doc
       RELEASE:clerk;                          release clerk

       QUEUE,  pullQ;                          matl issue queue
       SEIZE:  warehouseman;                   get warehouseman
       DELAY:  ED(6);                          pull & issue matl
       RELEASE:warehouseman;                   release
warehouseman
       DELAY:  0:NEXT(iss);                    go to pull loop

ca     BRANCH,1:                               !will cust take ca?
         WITH,.75,ca1:                         !cust accepts ca
         ELSE,a;                               Cust insists on a

ca1    BRANCH,1:                               !will ca satisfy
order?
         IF,CAINV.GE.qtyrqst,ca3:              !yes
         ELSE,ca2;                             no

ca2    ASSIGN: remqty=qtyrqst-CAINV:           !set remaining qty
               caqty=qtyrqst-remqty:           !set ca qty issued
               INVPOS=INVPOS-caqty:            !adjust inv
position
```

```
                INV=INV-caqty:                          !adjust total
inventory
                CAINV=CAINV-caqty;                       adjust ca inv
      DELAY: 0:NEXT(a1);                                 sent to a inv

ca3   ASSIGN: INVPOS=INVPOS-qtyrqst:                    !adjust inv position
                INV=INV-qtyrqst:                        !adjust total inv
                CAINV=CAINV-qtyrqst;                    !adjust ca inv
      DELAY:  0: NEXT(doc);                              go to doc prep
queue

a     BRANCH,1:                                         !will a satisfy order?
        IF,AINV.GE.qtyrqst,a3:                          !yes
        ELSE,a2;                                         no

a1    BRANCH,1:                                         !will a satisfy
remainder?
        IF,AINV.GE.remqty,all:                          !yes
        ESLE,a2;                                         no

a2    BRANCH,1:                                         !partial issue?
        IF,AINV.GE.1,some:                              !yes
        ELSE,back;                                       no

all   ASSIGN: INVPOS=INVPOS-remqty:                     !adjust inv
position
                INV=INV-remqty:                         !adjust total inv
```

```
            AINV=AINV-remqty;                              adjust a inv
      DELAY: 0:NEXT(doc);                                 go to doc prep
queue

some ASSIGN: short=MN(0,qtyrqst-caqty-AINV):              !establish amt
short
             aqty=qtyrqst-caqty-short:                    !establish a inv iss
             issqty=caqty+aqty:                           !reset issqty
             INVPOS=INVPOS-aqty:                          !adjust inv
position
             INV=INV-aqty:                                !adjust total inv
             AINV=AINV-aqty;                              adjust a inv
      DUPLICATE:1,back;                                   record shortage
cost
      DELAY: 0:NEXT(doc);                                 go to doc prep
queue

a3    ASSIGN: INVPOS=INVPOS-qtyrqst:                      !adjust inv position
             INV=INV-qtyrqst:                             !adjust total inv
            AINV=AINV-qtyrqst;                            adjust a inv
      DELAY:  0: NEXT(doc);                               go to doc prep
queue

;     Build pull matl loop

iss   BRANCH,1:                                           !all matl pulled?
         IF,issqty.GE.1,seek:                             !no, continue
```

```
        ELSE,goon1;                              yes, end loop

seek  SEARCH, hold1Q,1,2:MIN(SL);                find matl with
least
;                                                  SL remaining
      BRANCH,1:                                  !is queue empty?
        IF,J.EQ.0,bye:                           !yes
        ELSE,rem;                                 no
rem   REMOVE: J,hold1Q,temp;                      remove matl with
;                                                   least SL
remaining
      ASSIGN: issqty=issqty-1;                    adjust issqty for
;                                                   matl removed
      DELAY:  0:NEXT(iss);                        re-enter loop


goon1 COUNT:  DmdFrequency;                       record demand
freq
      DELAY:  0:NEXT(bye);                        disp of issue
action

temp DELAY:  ED(15):NEXT(camatl);                 issue matl to
cust

;     Receipt Routine Submodel

rev1  DUPLICATE:1,back:NEXT(camatl);              create dto
```

```
backorder

cont ASSIGN: TotalOrderCost=TotalOrderCost+OrderCost:          !adjust Total
Order Cost
               INVPOS=INVPOS+Qty:                              !adjust inv
position
               type=1:                                         !a cond matl
               OnOrder=OnOrder+Qty;                             adjust total on
order
     TALLY:  Order Cost,OrderCost;                              tally order cost


     QUEUE,  reorderQ;                                          reorder queue
     SEIZE:  clerk;                                            get clerk
     DELAY:  ED(1);                                             prepare reorder
     RELEASE:clerk;                                            release clerk

     DELAY:  ED(2);                                             delay shpg time

;    Material received

     ASSIGN: INV=INV+Qty:                                      !adjust total inv
               OnOrder=OnOrder-Qty:                            !adjust total on
order
               AINV=AINV+Qty:                                  !adjust a inv
               SL=TNOW+ED(16);                                  set shelf life
      QUEUE,  rcptQ;                                            rcpt queue
```

```
      SEIZE:  warehouseman;                                  get
warehouseman
      DELAY:  ED(4);                                         store matl
      RELEASE:warehouseman;                                  release
warehouseman

      DUPLICATE:Qty, hold1;                                  create each unit
of issue
      DELAY:  0:NEXT(cost);                                  send to cost calc

camatl ASSIGN: type=2:                                      !assign as ca matl
                 rtnqty=ED(17);                              unused matl
returned

      BRANCH,1:                                              !empty cont
returned?
         IF,rtnqty.EQ.0,bye:                                 !yes
         ELSE,camat;                                         no

camat QUEUE,  camatlQ;                                       ca matl queue
      SEIZE:  warehouseman;                                  get
warehousemen
      DELAY:  ED(3);                                         test for reuse
      BRANCH,1:                                              !matl reusable?
        WITH,.98,castow:                                     !reusable
        ELSE,other;                                          haz waste
```

```
castow DELAY: ED(4);                                    store reusable
matl
        RELEASE:warehouseman;                           release
warehouseman
        ASSIGN: INVPOS=INVPOS+rtnqty:                   !adjust inv
position
                INV=INV+rtnqty:                         !adjust total inv
                CAINV=CAINV+rtnqty;                      adjust ca inv
        DELAY: 0:NEXT(hold1);                            send to holding
area

;       Extension Routine Submodel

ext     BRANCH,1:                                       !what kind of
matl?
          IF,type.EQ.1,aext:                            !a matl
          ELSE,caext;                                    ca matl

;       Move from a to j condition while testing
;       Not available for issue or reorder evaluation while in j condition

aext  BRANCH,1:                                         !timing problem?
          IF,AINV.GT.0,aext1:                           !no
          ELSE,hold1;                                    yes

aext1 ASSIGN: INVPOS=INVPOS-1:                          !adjust inv
position
```

```
          INV=INV-1:                                    !adjust total inv
          AINV=AINV-1:                                  !adjust a inv
          TEMPINV=TEMPINV+1;                            adjust j inv
     DELAY:  0: NEXT(test);                             send matl for
test

;    Move from ca to j condition while testing
;    Not available for issue or reorder evaluation while in j condition

caext  BRANCH,1:                                        !timing problem?
       IF,CAINV.GT.0,caext1:                            !no
       ELSE,hold1;                                      yes

caext1ASSIGN: INVPOS=INVPOS-1:                          !adjust inv
position
          INV=INV-1:                                    !adjust total inv
          CAINV=CAINV-1:                                !adjust ca inv
          TEMPINV=TEMPINV+1;                            adjust j inv
     DELAY:  0: NEXT(test);                             send matl for
test

test   BRANCH,1:                                        !testable on site?
       WITH,.95,onsite:                                 !yes
       ELSE,ship;                                       no, send off
station

onsite BRANCH,1:
```

```
IF,DisposalCost+UnitCost+(OrderCost/Qty).GT.(LExtendCost+ExtendCost)/Xe,test1:
        ELSE,disp;

      QUEUE,  testQ;                                                on site test
queue
      SEIZE:  warehouseman;                                         get
warehouseman
      DELAY:  ED(7);                                                test matl
      RELEASE:warehouseman;                                         release
warehouseman

      ASSIGN: ExtendCostLocal=ExtendCostLocal+LExtendCost:          !adjust
Extension
;                                                                     Cost for local
test
              TotalExtendCost=TotalExtendCost+LExtendCost;          adjust Total
Extension
;                                                                     Cost
      TALLY:  Local Extension Cost, ExtendCostLocal;                tally local ext
test
      TALLY:  Total Extension Cost, TotalExtendCost;                tally total ext
cost

      BRANCH,1:                                                     !extendable?
        WITH,.80,extend:                                            !yes, extend
        ELSE,disp;                                                   no, haz waste
```

```
ship  BRANCH,1:

IF,DisposalCost+UnitCost+(OrderCost/Qty).GT.(LExtendCost+ExtendCost)/Xe,test2:
        ELSE,disp;

    DELAY: ED(9);                                                   shpg time
(round trp)

    ASSIGN: ExtendCostOther=ExtendCostOther+OExtendCost:           !adjust
Extension
;                                                                    Cost of other
;                                                                    location test
            TotalExtendCost=TotalExtendCost+OExtendCost;            adjust Total
Extension
;                                                                    Cost
    TALLY:  Other Extension Cost, ExtendCostOther;                  tally off site
test
    TALLY:  Total Extension Cost, TotalExtendCost;                  tally total ext
cost

    BRANCH,1:                                                       !extendable?
      WITH,.80,extend:                                              !yes, extend
      ELSE,disp;                                                    no, haz waste

extend QUEUE,  extendQ;                                             extension
queue
    SEIZE:  warehouseman;                                           get
```

```
warehouseman
     DELAY: ED(8);                                              mark matl for
exten
     DELAY: ED(4);                                              store matl
     RELEASE:warehouseman;                                      release
warehouseman

     ASSIGN: TotalExtendCost=TotalExtendCost+ExtendCost;        adjust Total
Extension
;                                                                 Cost
     TALLY: Non_Testing Extension Cost, ExtendCost;             tally label ext
cost
     TALLY: Total Extension Cost, TotalExtendCost;              tally total ext
cost

     BRANCH,1:                                                  !what kind of
matl?
        IF, type.EQ.1, aadd:                                    !a matl
        ELSE, caadd;                                            ca matl

aadd ASSIGN: INVPOS=INVPOS+1:                                   !adjust inv
position
              INV=INV+1:                                        !adjust total inv
              AINV=AINV+1:                                      !adjust a inv
              SL=TNOW+ED(10):                                   !set new
shelf-life
              TEMPINV=TEMPINV-1;                                adjust j inv
```

```
    DELAY:  0:NEXT(hold1);                                    return to
inventory

caadd ASSIGN: INVPOS=INVPOS+1:                                !adjust inv
position
              INV=INV+1:                                      !adjust total inv
              CAINV=CAINV+1:                                  !adjust ca inv
              SL=TNOW+ED(10):                                 !set new
shelf-life
              TEMPINV=TEMPINV-1;                              adjust j inv
    DELAY:  0:NEXT(hold1);                                    return to
inventory

hold1 QUEUE,  hold1Q;                                         units of issue
in stock
    SEIZE:  dummy;                                            dummy
resource
    RELEASE:dummy;                                            dummy
resource

;     Calculations and Disposals

back ASSIGN: backqty=backqty + 1;                             set backorder
qty
    TALLY:  Number of Backorders, backqty;                    tally
backorder qty
    ASSIGN: TotalBackCost=TotalBackCost+UnitBackCost;         adjust BB
```

```
Cost
     TALLY:  Backorder Cost,TotalBackCost;                          tally BB Cost
     DELAY:  0:NEXT(tvc);                                           send to Total
Annual
;                                                                     Cost

hold ASSIGN: HoldingCost=DAVG(hold1Q)*HoldCost*UnitCost:            !calc Hold
Cost
               TotalHoldCost=TotalHoldCost+HoldingCost;              calc Total
Hold Cost
     DELAY:  0:NEXT(tvc);                                            send to Total
Annual
;                                                                     Cost

cost  ASSIGN: InvCost=UnitCost*Qty:                                 !adjust Capital
Inv
;                                                                     Cost
               TotalInvCost=TotalInvCost+InvCost;                    adjust Total
Capital
;                                                                     Inv Cost
     TALLY:  Inventory Capital Cost,InvCost;                        tally capital
inv cost
     DELAY:  0:NEXT(tvc);                                           send to Total
Annual
;                                                                     Cost

;    Calculate various and total disposal costs
```

```
disp  ASSIGN:ExpiredDisposalCost=ExpiredDisposalCost+DisposalCost:NEXT(tot);
other ASSIGN:OtherDispCost=OtherDispCost+DisposalCost:NEXT(tot);
tot   ASSIGN:TotalDispCost=ExpiredDisposalCost+OtherDispCost;         calc total disp
cost
      TALLY: Disposal Cost_Expired Matl, ExpiredDisposalCost;
      TALLY: Disposal Cost_Other, OtherDispCost;
      TALLY: Total Disposal cost, TotalDispCost;                      tally total
cost
      DELAY: 0:NEXT(tvc);                                             send to Total
Annual
;                                                                      Cost
;     Caluclate total annual cost

tvc   ASSIGN:TotalVarCost=TotalInvCost+TotalHoldCost+TotalOrderCost:
            TotalOtherCost=TotalBackCost+TotalDispCost+TotalExtendCost:
            TotalAnnCost=TotalVarCost+TotalOtherCost;
      TALLY: Total Variable Cost, TotalAnnCost;                       tally tvc
      DELAY: 0:NEXT(bye);                                             dispose of
entities

bye   DELAY:  0: DISPOSE;

      END;
```

B. PROGRAM EXPERIMENT FRAME

```
      BEGIN;
```

```
;       Thesis Project

PROJECT, EOQ NSN, Stroh and Collins;

ATTRIBUTES:     SL:
                qtyrqst:
                qty,33:
                issqty:
                remqty:
                caqty:
                aqty:
                short:
                rtnqty:
                type;

VARIABLES:      CAINV:
                AINV:
                TEMPINV:
                Xe,40:
                OnOrder:
                ReorderPt,21:
                Rcpt:
                ExtendCost,1:
                TotalExtendCost:
                TotalOrderCost:
                ExpiredDisposalCost:
                DisposalCost,5:
```

```
            INVPOS:
            INV:
            backqty:
            UnitBackCost,23.5:
            TotalAnnCost:
            TotalOtherCost:
            InvCost:
            OtherDispCost:
            TotalDispCost:
            TotalVarCost:
            TotalInvCost:
            TotalHoldCost:
            HoldingCost:
            HoldCost,.21:
            UnitCost,80:
            OrderCost,53:
            TotalBackCost:
            ExtendCostLocal:
            ExtendCostOther:
            LextendCost,1.4:
            OextendCost,300:
            Demand;

EXPRESSIONS: 1,,EXPO(5,5):                      !order time
            2,,NORM(43800,21600,5):             !lead time
            3,,EXPO(7,5):                       !rtn test time
            4,,EXPO(20,5):                      !stow time
```

5,,EXPO(5,5): !doc prep

time

6,,EXPO(20,5): !issue time

7,,EXPO(7,5): !ext test

time

8,,EXPO(5,5): !ext time

9,,UNIF(10080,30160,5): !off site test

time

10,,262800: !extended

SL

11,,EXPO(10512,5): !order freq

12,,NORM(4.0,2.1,5): !order qty

13,,10080: !reorder

frequency

14,,43800: !SL rev

frequency

15,,EXPO(10080,5): !customer

has matl

16,,UNIF(131400,219000,5): !initial SL

17,,DISC(.90,0,1,1,5); returned

quantity

QUEUES: docQ:

pullQ:

reorderQ:

rcptQ:

testQ:

```
          extendQ:
          camatlQ:
          hold1Q,LVF(SL);

RESOURCES:  clerk,2:
            dummy,0:
            warehouseman,10;

RANKINGS:   hold1Q,LVF(SL);

TALLIES:    1,Number of Backorders, "c:\arena\BBs1.dat":
            2,Backorder Cost, "c:\arena\BB1.dat":
            3,Inventory Capital Cost, "c:\arena\invcap1.dat":
            4,Order Cost, "c:\arena\order1.dat":
            5,Local Extension Cost, "c:\arena\lext1.dat":
            6,Other Extension Cost, "c:\arena\oext1.dat":
            7,Non_Testing Extension Cost, "c:\arena\ntext.dat":
            8,Total Extension Cost, "c:\arena\totext1.dat":
            9,Disposal Cost_Expired Matl, "c:\arena\disexp1.dat":
            10,Disposal Cost_Other, "c:\arena\disoth1.dat":
            11,Total Disposal Cost, "c:\arena\totdis1.dat":
            12Total Variable Cost, "c:\arena\tvc1.dat";

OUTPUTS:    Demand,, Item Demand:
            AINV,, A Cond Inv:
            CAINV,, CA Cond Inv:
            INV,,Total Avail Inv:
```

```
                TEMPINV,, Cand for Ext:
                OnOrder,, On Order:
                INVPOS,, Inventory Position:
                TotalOrderCost,, Total Order Cost:
                TotalExtendCost,, Total Extension Cost:
                TotalBackCost,, Total Backorder Cost:
                TotalInvCost,, Total Capital Inv Cost:
                TotalHoldCost,, Total Holding Cost:
                ExpiredDisposalCost,, Disposal Cost Expired Matl:
                OtherDispCost,, Disposal Cost Used Matl Residue:
                TotalDispCost,, Total Disposal Cost:
                TotalAnnCost,, Total Variable Cost;

    COUNTERS:   DmdFrequency;

    DSTAT:      NQ(docQ), Issue Document Processing:
                NQ(pullQ), Material Issue:
                NQ(reorderQ), Reorder Processing:
                NQ(rcptQ), Receipt Processing:
                NQ(testQ), SL Extentsion Testing:
                NQ(extendQ), SL Extension Processing:
                NQ(camatlQ), CA Material Processing:
                NQ(hold1Q),Holding Area:
                NR(clerk), clerk Utilization:
                NR(warehouseman), Warehouseman Utilization;

REPLICATE,4,0,525600,No,Yes,87600;
```

END;

C. SAMPLE OUTPUT DATA

SIMAN V - License #9999999

Systems Modeling Corporation

Summary for Replication 4 of 4

Project: EOQ NSN Run execution date : 11/25/1995

Analyst: Stroh and Collins Model revision date: 11/25/1995

Replication ended at time: 2.19e+006

Statistics were cleared at time: 1.6644e+006

Statistics accumulated for time: 525600.0

TALLY VARIABLES

Identifier	Average	Variation	Minimum	Maximum	Observations
Number of Backorders	14.000	.00000	14.000	14.000	1
Backorder Cost	329.00	.00000	329.00	329.00	1

Inventory Capital Cost	2640.0	.00000	2640.0	2640.0	4
Order Cost	53.000	.00000	53.000	53.000	5
Local Extension Cost	30.100	.14082	23.800	36.400	10
Other Extension Cost	450.00	.47140	300.00	600.00	2
Non_Testing Extension	1.0000	.00000	1.0000	1.0000	10
Total Extension Cost	798.54	.45661	37.800	660.40	22
Disposal Cost_Expired	17.500	.20203	15.000	20.000	2
Disposal Cost_Other	10.000	.00000	10.000	10.000	2
Total Disposal Cost	27.500	.12856	25.000	30.000	2
Total Variable Cost	53366.	.07642	49352.	59942.	8

DISCRETE-CHANGE VARIABLES

Identifier	Average	Variation	Minimum	Maximum	Final Value
Issue Document Processing	.00000	--	.00000	.00000	

.00000				
Material Issue	.00000	--	.00000	.00000
.00000				
Reorder Processing	.00000	--	.00000	.00000
.00000				
Receipt Processing	.00000	--	.00000	.00000
.00000				
SL Extentsion Testing	.00000	--	.00000	.00000
.00000				
SL Extension Processing	.00000	--	.00000	.00000
.00000				
CA Material Processing	.00000	--	.00000	.00000
.00000				
Holding Area	111.34	.11103	87.000	136.00
97.000				
Clerk Utilization	4.5934E-04	48.988	.00000	2.0000
.00000				
Warehouseman Utilization	2.0028	.02669	.00000	4.0000
3.0000				

COUNTERS

Identifier	Count	Limit
DmdFrequency	39	Infinite

OUTPUTS

Identifier	Value
Item Demand	753.49
A Cond Inv	.31354
CA Cond Inv	1.0000
Total Avail Inv	1.3135
Cand for Ext	5.0000
On Order	33.000
Inventory Position	34.313
Total Order Cost	1113.0
Total Extension Cost	660.40
Total Backorder Cost	329.00
Total Capital Inv Cost	52800.
Total Holding Cost	5068.0
Disposal Cost Expired	20.000
Disposal Cost Used Mat	10.000
Total Disposal Cost	30.000
Total Variable Cost	59942.

Execution time: 0.10 minutes.

Simulation run complete.

APPENDIX D. MODIFIED SILVER MODEL (SIMAN PROGRAM)

A. PROGRAM MODEL FRAME

```
     BEGIN;

;    Thesis HAZMINCEN Mod-Silver Simulation, Stroh and Collins

;    General Information
;         Time is counted in units of minutes, periods are in units of months (43800 min)
;         The model runs only one line item at a time
;         Processing times are based on info provided by HAZMINCEN,
;           Point Mugu
;         Mod-Silver Model Version
;         Input factors are ReorderPt and Demand Factors (x1,x2, etc.)

;    Create orders

     CREATE: ED(11);                                        orders
     ASSIGN: qtyrqst=ED(12):                               !determine qty
rqstd
              issqty=qtyrqst:                              !establish qty
issued
              Demand=Demand+qtyrqst:NEXT(order);            record demand

;    Create holding cost calculation trigger
```

```
     CREATE,1,525599:525599:NEXT(hold);                          hold cost calc trig

;    Create reorder review action

     CREATE,1,ED(13):ED(13);                                     conduct reorder
rev
     ASSIGN: Ka=(INVPOS-x1)/StdDevx1;                            calculate Ka
     BRANCH,1:                                                   !reorder required?
       IF,Ka.LE.Kr,rev:                                          !yes
       ELSE,bye;                                                  no

;    Create shelf-life expiration review action

     CREATE,1,ED(14):ED(14);                                     conduct SL
review
     SEARCH, hold1Q,1,NQ:TNOW.GE.SL;                             ID expired matl
     BRANCH, 1:                                                  !is queue empty?
       IF,J.EQ.0,bye:                                            !yes
       ELSE, rem1;                                                no
rem1REMOVE: J,hold1Q,ext;                                        send to extend
submod
     DELAY:  0:NEXT(bye);                                        dispose of rev
action

;    Issue Routine Submodel

order   BRANCH,1:                                                !check inv on hand
```

```
        IF,CAINV.GE.qtyrqst,ca:                    !issue ca matl
        IF,AINV.GE.qtyrqst,a:                      !issue a matl
        ELSE,back;                                  conduct reorder
rev

doc     QUEUE,  docQ;                              issue doc queue
        SEIZE:  clerk;                             get clerk
        DELAY:  ED(5);                             make issue doc
        RELEASE:clerk;                             release clerk

        QUEUE,  pullQ;                             matl issue queue
        SEIZE:  warehouseman;                      get warehouseman
        DELAY:  ED(6);                             pull & issue matl
        RELEASE:warehouseman;                      release
warehouseman
        DELAY:  0:NEXT(iss);                       go to pull loop


ca      BRANCH,1:                                  !will cust take ca?
          WITH,.75,ca1:                            !cust accepts ca
          ELSE,a;                                  Cust insists on a

ca1     BRANCH,1:                                  !will ca satisfy
order?
          IF,CAINV.GE.qtyrqst,ca3:                 !yes
          ELSE,ca2;                                no
```

```
ca2    ASSIGN: remqty=qtyrqst-CAINV:                    !set remaining qty
               caqty=qtyrqst-remqty:                    !set ca qty issued
               INVPOS=INVPOS-caqty:                     !adjust inv
position
               INV=INV-caqty:                           !adjust total
inventory
               CAINV=CAINV-caqty;                        adjust ca inv
       DELAY: 0:NEXT(a1);                                sent to a inv

ca3    ASSIGN: INVPOS=INVPOS-qtyrqst:                   !adjust inv position
               INV=INV-qtyrqst:                         !adjust total inv
               CAINV=CAINV-qtyrqst;                     !adjust ca inv
       DELAY:  0: NEXT(doc);                             go to doc prep
queue

a      BRANCH,1:                                        !will a satisfy order?
         IF,AINV.GE.qtyrqst,a3:                         !yes
         ELSE,a2;                                        no

a1     BRANCH,1:                                        !will a satisfy
remainder?
         IF,AINV.GE.remqty,all:                         !yes
         ESLE,a2;                                        no

a2     BRANCH,1:                                        !partial issue?
         IF,AINV.GE.1,some:                             !yes
         ELSE,back;                                      no
```

```
all    ASSIGN: INVPOS=INVPOS-remqty:                    !adjust inv
position
               INV=INV-remqty:                          !adjust total inv
               AINV=AINV-remqty;                         adjust a inv
       DELAY: 0:NEXT(doc);                               go to doc prep
queue

some ASSIGN: short=MN(0,qtyrqst-caqty-AINV):            !establish amt
short
               aqty=qtyrqst-caqty-short:                !establish a inv iss
               issqty=caqty+aqty:                       !reset issqty
               INVPOS=INVPOS-aqty:                      !adjust inv
position
               INV=INV-aqty:                            !adjust total inv
               AINV=AINV-aqty;                           adjust a inv
       DUPLICATE:1,back;                                 record shortage
cost
       DELAY: 0:NEXT(doc);                               go to doc prep
queue

a3     ASSIGN: INVPOS=INVPOS-qtyrqst:                   !adjust inv position
               INV=INV-qtyrqst:                         !adjust total inv
               AINV=AINV-qtyrqst;                        adjust a inv
       DELAY:  0: NEXT(doc);                             go to doc prep
queue

;      Build pull matl loop
```

```
iss     BRANCH,1:                                   !all matl pulled?
          IF,issqty.GE.1,seek:                      !no, continue
          ELSE,goon1;                               yes, end loop

seek  SEARCH, hold1Q,1,2:MIN(SL);                   find matl with least
;                                                      SL remaining
       BRANCH,1:                                    !is queue empty?
         IF,J.EQ.0,bye:                             !yes
         ELSE,rem;                                   no
rem   REMOVE: J,hold1Q,temp;                         remove matl with
;                                                      least SL
remaining
       ASSIGN: issqty=issqty-1;                      adjust issqty for
;                                                     matl removed
       DELAY:  0:NEXT(iss);                          re-enter loop


goon1 COUNT:  DmdFrequency;                          record demand
freq
       DELAY:  0:NEXT(bye);                          disp of issue
action

temp DELAY:  ED(15):NEXT(camatl);                    issue matl to
cust

;      Receipt Routine Submodel
```

```
rev   ASSIGN: Qty=x2+(b*StdDevx2)+x3+(Kr*StdDevx3)-INVPOS;   calc order qty
      BRANCH,1:                                                !is order qty
negative?
         IF,Qty.LE.0,bye:                                      !yes, dispose
         ELSE,cont;                                             no, continue

cont ASSIGN: TotalOrderCost=TotalOrderCost+OrderCost:          !adjust Total
Order Cost
              INVPOS=INVPOS+Qty:                               !adjust inv
position
              type=1:                                          !a cond matl
              OnOrder=OnOrder+Qty;                               adjust total on
order
      TALLY:  Order Cost,OrderCost;                             tally order cost


      QUEUE,  reorderQ;                                         reorder queue
      SEIZE:  clerk;                                           get clerk
      DELAY:  ED(1);                                            prepare reorder
      RELEASE:clerk;                                           release clerk

      DELAY:  ED(2);                                            delay shpg time

;     Material received

        ASSIGN: INV=INV+Qty:                                   !adjust total inv
                OnOrder=OnOrder-Qty:                           !adjust total on
```

```
order
                    AINV=AINV+Qty:                              !adjust a inv
                    SL=TNOW+ED(16);                             set shelf life
          QUEUE,  rcptQ;                                        rcpt queue
          SEIZE:  warehouseman;                                 get
warehouseman
          DELAY:  ED(4);                                        store matl
          RELEASE:warehouseman;                                 release
warehouseman

          DUPLICATE:Qty, hold1;                                 create each unit
of issue
          DELAY:  0:NEXT(cost);                                 send to cost calc

camatl ASSIGN: type=2:                                          !assign as ca matl
                    rtnqty=ED(17);                              unused matl
returned

          BRANCH,1:                                             !empty cont
returned?
            IF,rtnqty.EQ.0,bye:                                 !yes
            ELSE,camat;                                         no

camat QUEUE,  camatlQ;                                          ca matl queue
         SEIZE:  warehouseman;                                  get
warehousemen
         DELAY:  ED(3);                                         test for reuse
```

```
        BRANCH,1:                                    !matl reusable?
          WITH,.98,castow:                           !reusable
          ELSE,other;                                 haz waste

castow DELAY:  ED(4);                                 store reusable
matl
        RELEASE:warehouseman;                         release
warehouseman
        ASSIGN: INVPOS=INVPOS+rtnqty:                !adjust inv
position
                INV=INV+rtnqty:                      !adjust total inv
                CAINV=CAINV+rtnqty;                   adjust ca inv
        DELAY:  0:NEXT(hold1);                        send to holding
area

;       Extension Routine Submodel

ext     BRANCH,1:                                    !what kind of
matl?
          IF,type.EQ.1,aext:                         !a matl
          ELSE,caext;                                 ca matl

;       Move from a to j condition while testing
;       Not available for issue or reorder evaluation while in j condition

aext    BRANCH,1:                                    !timing problem?
          IF,AINV.GT.0,aext1:                        !no
```

```
        ELSE,hold1;                                  yes

aext1  ASSIGN: INVPOS=INVPOS-1:                      !adjust inv
position
                  INV=INV-1:                         !adjust total inv
                  AINV=AINV-1:                       !adjust a inv
                  TEMPINV=TEMPINV+1;                  adjust j inv
       DELAY:  0: NEXT(test);                         send matl for
test

;      Move from ca to j condition while testing
;      Not available for issue or reorder evaluation while in j condition

caext  BRANCH,1:                                     !timing problem?
         IF,CAINV.GT.0,caext1:                       !no
         ELSE,hold1;                                  yes

caext1ASSIGN: INVPOS=INVPOS-1:                       !adjust inv
position
                  INV=INV-1:                         !adjust total inv
                  CAINV=CAINV-1:                     !adjust ca inv
                  TEMPINV=TEMPINV+1;                  adjust j inv
       DELAY:  0: NEXT(test);                         send matl for
test

test   BRANCH,1:                                     !testable on site?
         WITH,.95,onsite:                            !yes
```

```
        ELSE,ship;                                              no, send off
station

onsite BRANCH,1:
IF,DisposalCost+UnitCost+((OrderCost*12/T)/DMD).GE.(LExtendCost+ExtendCost)/X
e,test1:
ELSE,disp;

        QUEUE,  testQ;                                          on site test
queue
        SEIZE:  warehouseman;                                   get
warehouseman
        DELAY:  ED(7);                                          test matl
        RELEASE:warehouseman;                                   release
warehouseman

        ASSIGN: ExtendCostLocal=ExtendCostLocal+LExtendCost:    !adjust
Extension
;                                                                 Cost for local
test
                TotalExtendCost=TotalExtendCost+LExtendCost;    adjust Total
Extension
;                                                                 Cost

        TALLY:  Local Extension Cost, ExtendCostLocal;          tally local ext
test
        TALLY:  Total Extension Cost, TotalExtendCost;          tally total ext
```

```
cost

        BRANCH,1:                                                  !extendable?
          WITH,.80,extend:                                         !yes, extend
          ELSE,disp;                                                no, haz waste

ship   BRANCH,1:
IF,DisposalCost+UnitCost+((OrderCost*12/T)/DMD).GT.(LExtendCost+ExtendCost)/X
e,test2:
ELSE,disp;

        DELAY:  ED(9);                                              shpg time
(round trp)

        ASSIGN: ExtendCostOther=ExtendCostOther+OExtendCost:       !adjust
Extension
;                                                                   Cost of other
;                                                                   location test
                TotalExtendCost=TotalExtendCost+OExtendCost;        adjust Total
Extension
;                                                                   Cost
        TALLY:  Other Extension Cost, ExtendCostOther;              tally off site
test
        TALLY:  Total Extension Cost, TotalExtendCost;              tally total ext
cost

        BRANCH,1:                                                  !extendable?
```

```
        WITH,.80,extend:                                         !yes, extend
        ELSE,disp;                                                no, haz waste

extend QUEUE,  extendQ;                                           extension
queue
      SEIZE:  warehouseman;                                       get
warehouseman
      DELAY:  ED(8);                                              mark matl for
exten
      DELAY:  ED(4);                                              store matl
      RELEASE:warehouseman;                                       release
warehouseman

      ASSIGN: TotalExtendCost=TotalExtendCost+ExtendCost;         adjust Total
Extension
;                                                                   Cost
      TALLY:  Non_Testing Extension Cost, ExtendCost;             tally label ext
cost
      TALLY:  Total Extension Cost, TotalExtendCost;              tally total ext
cost

      BRANCH,1:                                                  !what kind of
matl?
        IF, type.EQ.1, aadd:                                     !a matl
        ELSE, caadd;                                              ca matl

aadd ASSIGN: INVPOS=INVPOS+1:                                    !adjust inv
```

```
position
              INV=INV+1:                                 !adjust total inv
              AINV=AINV+1:                               !adjust a inv
              SL=TNOW+ED(10):                            !set new
shelf-life
              TEMPINV=TEMPINV-1;                          adjust j inv
     DELAY:  0:NEXT(hold1);                               return to
inventory

caadd ASSIGN: INVPOS=INVPOS+1:                           !adjust inv
position
              INV=INV+1:                                 !adjust total inv
              CAINV=CAINV+1:                             !adjust ca inv
              SL=TNOW+ED(10):                            !set new
shelf-life
              TEMPINV=TEMPINV-1;                          adjust j inv
     DELAY:  0:NEXT(hold1);                               return to
inventory

hold1 QUEUE,  hold1Q;                                     units of issue
in stock
     SEIZE:  dummy;                                       dummy
resource
     RELEASE:dummy;                                       dummy
resource

;       Calculations and Disposals
```

```
back ASSIGN: backqty=backqty + 1;                               set backorder
qty
     TALLY:  Number of Backorders, backqty;                      tally
backorder qty
     ASSIGN: TotalBackCost=TotalBackCost+UnitBackCost;          adjust BB
Cost
     TALLY:  Backorder Cost,TotalBackCost;                      tally BB Cost
     DELAY:  0:NEXT(tvc);                                       send to Total
Annual
;                                                                 Cost
hold ASSIGN: HoldingCost=DAVG(hold1Q)*HoldCost*UnitCost:        !calc Hold
Cost
              TotalHoldCost=TotalHoldCost+HoldingCost;           calc Total
Hold Cost
     DELAY:  0:NEXT(tvc);                                        send to Total
Annual
;                                                                  Cost

cost  ASSIGN: InvCost=UnitCost*Qty:                             !adjust Capital
Inv
;                                                                  Cost
              TotalInvCost=TotalInvCost+InvCost;                adjust Total
Capital
;                                                                  Inv Cost
     TALLY:  Inventory Capital Cost,InvCost;                    tally capital
inv cost
     DELAY:  0:NEXT(tvc);                                       send to Total
```

```
Annual
;                                                                    Cost

;     Calculate various and total disposal costs

disp  ASSIGN:ExpiredDisposalCost=ExpiredDisposalCost+DisposalCost:NEXT(tot);
other ASSIGN:OtherDispCost=OtherDispCost+DisposalCost:NEXT(tot);
tot   ASSIGN:TotalDispCost=ExpiredDisposalCost+OtherDispCost;        calc total disp
cost
      TALLY: Disposal Cost_Expired Matl, ExpiredDisposalCost;
      TALLY: Disposal Cost_Other, OtherDispCost;
      TALLY: Total Disposal cost, TotalDispCost;                     tally total
cost
      DELAY: 0:NEXT(tvc);                                            send to Total
Annual
;                                                                    Cost

;     Caluclate total annual cost

tvc   ASSIGN:TotalVarCost=TotalInvCost+TotalHoldCost+TotalOrderCost:
              TotalOtherCost=TotalBackCost+TotalDispCost+TotalExtendCost:
              TotalAnnCost=TotalVarCost+TotalOtherCost;
      TALLY: Total Variable Cost, TotalAnnCost;                      tally tvc
      DELAY: 0:NEXT(bye);                                            dispose of
entities

bye   DELAY: 0: DISPOSE;
```

```
END;
```

B. PROGRAM EXPERIMENT FRAME

```
BEGIN;
;       Thesis Project
        PROJECT, Mod NSN, Stroh and Collins;

        ATTRIBUTES:     SL:
                        qtyrqst:
                        qty:
                        issqty:
                        remqty:
                        caqty:
                        aqty:
                        short:
                        rtnqty:
                        type;

        VARIABLES:      CAINV:
                        AINV:
                        HL:
                        DMD,200:
                        T,3:
                        b,.5:
                        x1,20:
                        x2,20:
```

x3,21:

StdDevx1,8.55:

StdDevx2,7.01:

StdDevx3,9.63:

Kr,2.33: !99% SL

Ka:

TEMPINV:

Xe,40:

OnOrder:

ReorderPt:

Rcpt:

ExtendCost,1:

TotalExtendCost:

TotalOrderCost:

ExpiredDisposalCost:

DisposalCost,5:

INVPOS:

INV:

backqty:

UnitBackCost,23.5:

TotalAnnCost:

TotalOtherCost:

InvCost:

OtherDispCost:

TotalDispCost:

TotalVarCost:

TotalInvCost:

```
                TotalHoldCost:
                HoldingCost:
                HoldCost,.21:
                UnitCost,80:
                OrderCost,53:
                TotalBackCost:
                ExtendCostLocal:
                ExtendCostOther:
                LextendCost,1.4:
                OextendCost,300:
                Demand;

EXPRESSIONS:    1,,EXPO(5,5):                       !order time
                2,,NORM(43800,21600,5):             !lead time
                3,,EXPO(7,5):                       !rtn test time
                4,,EXPO(20,5):                      !stow time
                5,,EXPO(5,5):                       !doc prep
time
                6,,EXPO(20,5):                      !issue time
                7,,EXPO(7,5):                       !ext test
time
                8,,EXPO(5,5):                       !ext time
                9,,UNIF(10080,30160,5):             !off site test
time
                10,,262800:                         !extended
SL
                11,,EXPO(10512,5):                  !order freq
```

```
                12,,NORM(4.0,2.1,5):                          !order qty
                13,,131400:                                   !reorder
frequency
                14,,43800:                                    !SL rev
frequency
                15,,EXPO(10080,5):                            !customer
has matl
                16,,UNIF(131400,219000,5):                    !initial SL
                17,,DISC(.90,0,1,1,5);                         returned
quantity

   QUEUES:      docQ:
                pullQ:
                reorderQ:
                rcptQ:
                testQ:
                extendQ:
                camatlQ:
                hold1Q,LVF(SL);

   RESOURCES:   clerk,2:
                dummy,0:
                warehouseman,10;

   RANKINGS:    hold1Q,LVF(SL);

   TALLIES:     1,Number of Backorders, "c:\arena\BBs1.dat":
```

2,Backorder Cost, "c:\arena\BB1.dat":

3,Inventory Capital Cost, "c:\arena\invcap1.dat":

4,Order Cost, "c:\arena\order1.dat":

5,Local Extension Cost, "c:\arena\lext1.dat":

6,Other Extension Cost, "c:\arena\oext1.dat":

7,Non_Testing Extension Cost, "c:\arena\ntext.dat":

8,Total Extension Cost, "c:\arena\totext1.dat":

9,Disposal Cost_Expired Matl, "c:\arena\disexp1.dat":

10,Disposal Cost_Other, "c:\arena\disoth1.dat":

11,Total Disposal Cost, "c:\arena\totdis1.dat":

12Total Variable Cost, "c:\arena\tvc1.dat";

OUTPUTS: Demand,, Item Demand:

AINV,, A Cond Inv:

CAINV,, CA Cond Inv:

INV,,Total Avail Inv:

TEMPINV,, Cand for Ext:

OnOrder,, On Order:

INVPOS,, Inventory Position:

TotalOrderCost,, Total Order Cost:

TotalExtendCost,, Total Extension Cost:

TotalBackCost,, Total Backorder Cost:

TotalInvCost,, Total Capital Inv Cost:

TotalHoldCost,, Total Holding Cost:

ExpiredDisposalCost,, Disposal Cost Expired Matl:

OtherDispCost,, Disposal Cost Used Matl Residue:

TotalDispCost,, Total Disposal Cost:

TotalAnnCost,, Total Variable Cost;

COUNTERS: DmdFrequency;

DSTAT: NQ(docQ), Issue Document Processing:
NQ(pullQ), Material Issue:
NQ(reorderQ), Reorder Processing:
NQ(rcptQ), Receipt Processing:
NQ(testQ), SL Extentsion Testing:
NQ(extendQ), SL Extension Processing:
NQ(camatlQ), CA Material Processing:
NQ(hold1Q), Holding Area:
NR(clerk), clerk Utilization:
NR(warehouseman), Warehouseman Utilization;

REPLICATE,4,0,525600,No,Yes,87600;
END;

C. SAMPLE OUTPUT DATA

SIMAN V - License #9999999
Systems Modeling Corporation

Summary for Replication 4 of 4

Project: Mod NSN Run execution date :
11/25/1995

Analyst: Stroh and Collins Model revision date: 11/25/1995

Replication ended at time: 2.19e+006

Statistics were cleared at time: 1.6644e+006

Statistics accumulated for time: 525600.0

TALLY VARIABLES

Identifier	Average	Variation	Minimum	Maximum	Observations
Number of Backorders	15.500	.23262	10.000	21.000	12
Backorder Cost	364.25	.23262	235.30	493.50	12
Inventory Capital Cost	4274.1	.34063	2665.8	5502.2	3
Order Cost	53.000	.00000	53.000	53.000	3
Local Extension Cost	54.600	.07022	49.000	60.200	9
Other Extension Cost	--	--	--	--	0
Non_Testing Extension	1.0000	.00000	1.0000	1.0000	8

Total Extension Cost	83.647	.07317	74.000	93.200	17
Disposal Cost_Expired	50.000	.00000	50.000	50.000	1
Disposal Cost_Other	5.0000	.00000	.5.0000	5.0000	1
Total Disposal Cost	55.000	.00000	55.000	55.000	1
Total Variable Cost	47370.	.09735	42753.	57386.	17

DISCRETE-CHANGE VARIABLES

Identifier	Average	Variation	Minimum	Maximum	Final Value
Issue Document Processing	.00000	--	.00000	.00000	.00000
Material Issue	.00000	--	.00000	.00000	.00000
Reorder Processing	.00000	--	.00000	.00000	.00000
Receipt Processing	.00000	--	.00000	.00000	.00000
SL Extentsion Testing	.00000	--	.00000	.00000	.00000

SL Extension Processing .00000 -- .00000 .00000
.00000
CA Material Processing .00000 -- .00000 .00000
.00000
Holding Area 84.257 .28324 55.000 124.00
119.00 Clerk Utilization 3.3341E-04 54.757 .00000 1.0000
.00000
Warehouseman Utilization 1.0027 .05216 1.0000 2.0000
2.0000

COUNTERS

Identifier	Count	Limit
DmdFrequency	32	Infinite

OUTPUTS

Identifier	Value
Item Demand	718.89
A Cond Inv	48.688
CA Cond Inv	.00000
Total Avail Inv	48.688
Cand for Ext	11.000
On Order	.00000
Inventory Position	48.688

Total Order Cost	689.00
Total Extension Cost	93.200
Total Backorder Cost	493.50
Total Capital Inv Cost	51557.
Total Holding Cost	4498.0
Disposal Cost Expired	50.000
Disposal Cost Used Mat	5.0000
Total Disposal Cost	55.000
Total Variable Cost	57386.

Execution time: 0.10 minutes.

Simulation run complete.

APPENDIX E. INVENTORY COSTS SUMMARIES

A. SUMMARY OF SIMULATION CHANGES

Scenario #1: Quantity of material returned increased from 10% to 20%.

Scenario #2: Shelf-life changed from six months with a single equivalent length of extension, to twelve months with a single equivalent length extension.

Scenario #3: Percentage of customers willing to accept CA material decreased from 75% to 50%.

Scenario #4: Percentage of material that fails test for extension increased from 20% to 40%.

B. INVENTORY COSTS

Change/Model	EOQ	MOD
Basic	$62,094	$57,386
Scenario #1	$57,276	$63,219
Scenario #2	$59,223	$58,853
Scenario #3	$56,717	$65,581
Scenario #4	$64,116	$61,847

Table E.1. Total Variable Costs Summary.

Change/Model	EOQ	MOD
Basic	$55,440	$51,557
Scenario #1	$50,160	$56,767
Scenario #2	$52,800	$52,777
Scenario #3	$50,160	$59,116
Scenario #4	$58,080	$55,460

Table E.2. Purchase Costs Summary.

Change/Model	EOQ	MOD
Basic	$1,113	$689
Scenario #1	$1,060	$795
Scenario #2	$1,113	$795
Scenario #3	$1,007	$742
Scenario #4	$1,219	$689

Table E.3. Order Costs Summary.

Change/Model	EOQ	MOD
Basic	$4234	$4,498
Scenario #1	$4,267	$4684
Scenario #2	$4,086	$4,853
Scenario #3	$4,122	$4,808
Scenario #4	$3957	$4,325

Table E.4. Holding Costs Summary.

Change/Model	EOQ	MOD
Basic	$870	$494
Scenario #1	$799	$494
Scenario #2	$517	$259
Scenario #3	$705	$470
Scenario #4	$729	$588

Table E.5. Backorder Costs Summary.

Change/Model	EOQ	MOD
Basic	$55	$55
Scenario #1	$50	$60
Scenario #2	$60	$70
Scenario #3	$35	$50
Scenario #4	$95	$105

Table E.6. Disposal Costs Summary.

Change/Model	EOQ	MOD
Basic	$383	$93
Scenario #1	$993	$392
Scenario #2	$701	$99
Scenario #3	$691	$397
Scenario #4	$94	$681

Table E.7. Extension Costs Summary.

APPENDIX F. SIMULATION RESULTS

A. SIMULATION RESULTS

1. Basic Version

Costs/Model	EOQ	MOD
TVC	$62,094	$57,386
Purchase	$55,440	$51,557
Order	$1,113	$689
Holding	$4,234	$4,498
Backorder	$870	$494
Disposal	$55	$55
Extension	$383	$93

Table F.2. Basic Version Models' Costs Summaries.

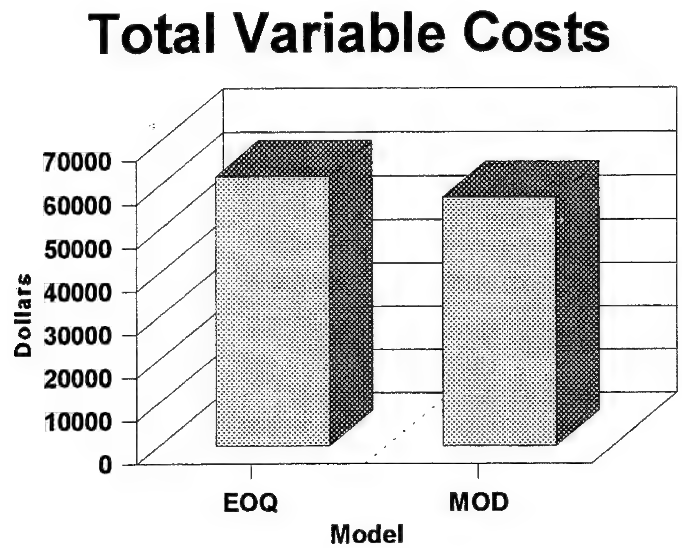

Figure F.1. Basis Version TVC Comparison

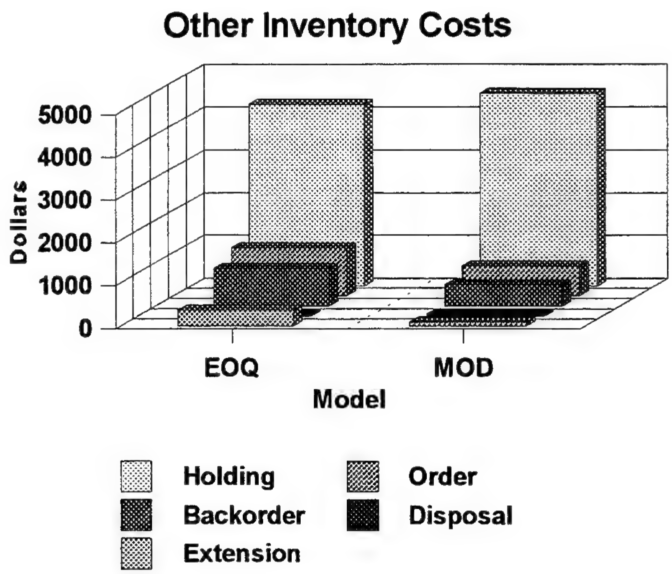

Figure F.2. Basic Version Costs Comparison

2. Scenario #1 simulation results (Quantity of material returned increased from 10% to 20%)

Costs/Model	EOQ	MOD
TVC	$57,276	$63,219
Purchase	$50,160	$56,767

Order	$1,060	$795
Holding	$4,267	$4,684
Backorder	$799	$494
Disposal	$50	$60
Extension	$993	$392

Table F.3. Scenario #1 Models' Costs Summaries.

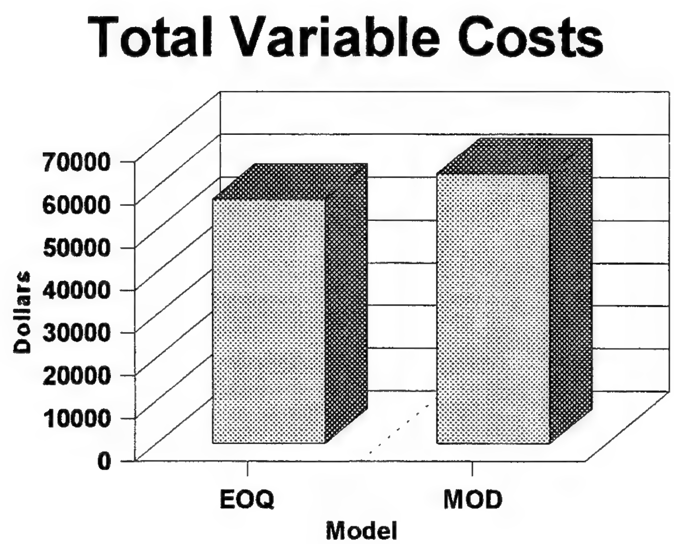

Figure F.3. Scenario #1 TVC Comparison

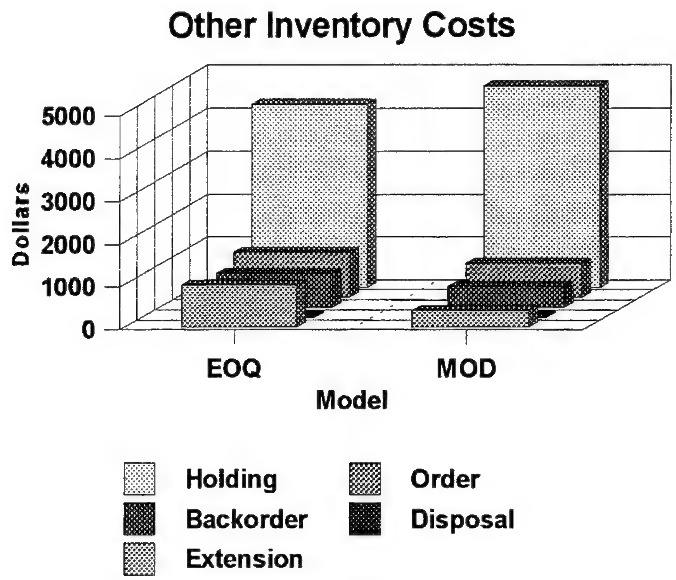

Figure F.4. Scenario #1 Costs Comparison

3. **Scenario #2 simulation results (Shelf-life changed from six months to twelve months)**

Costs/Model	EOQ	MOD
TVC	$59,223	$58,853
Purchase	$52,800	$52,777
Order	$1,113	$795
Holding	$4,086	$4,853
Backorder	$517	$259
Disposal	$60	$70
Extension	$701	$99

Table F.4. Scenario #2 Models' Costs Summaries.

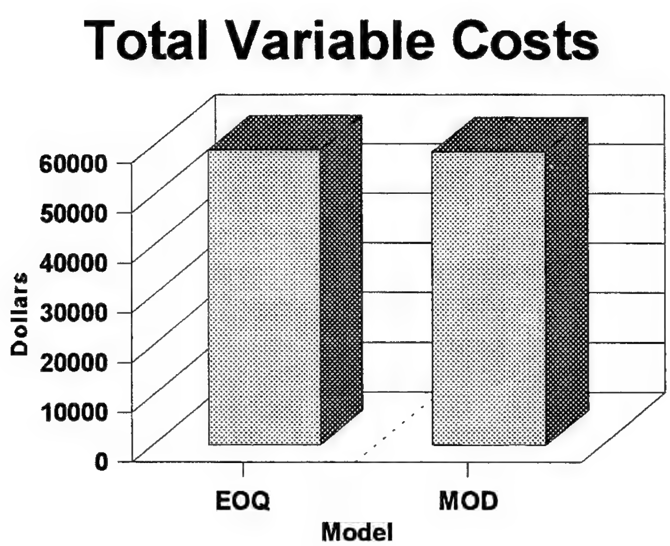

Figure F.5. Scenario #2 TVC Comparison

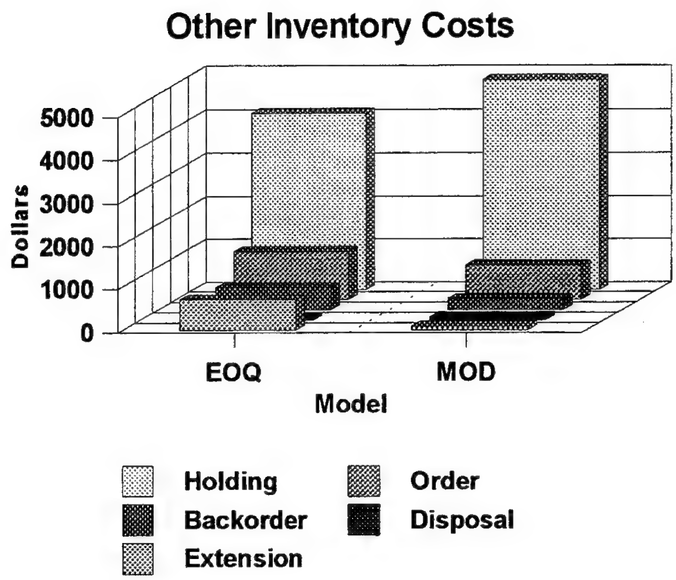

Figure F.6. Scenario #2 Costs Comparison

4. Scenario #3 simulation results (percentage of customers willing ot accept CA material decreased from 75% to 50%)

Costs/Model	EOQ	MOD

TVC	$56,717	$65,581
Purchase	$50,160	$59,116
Order	$1,007	$742
Holding	$4,122	$4,808
Backorder	$705	$470
Disposal	$35	$50
Extension	$691	$397

Table F.5. Scenario #3 Models' Costs Summaries.

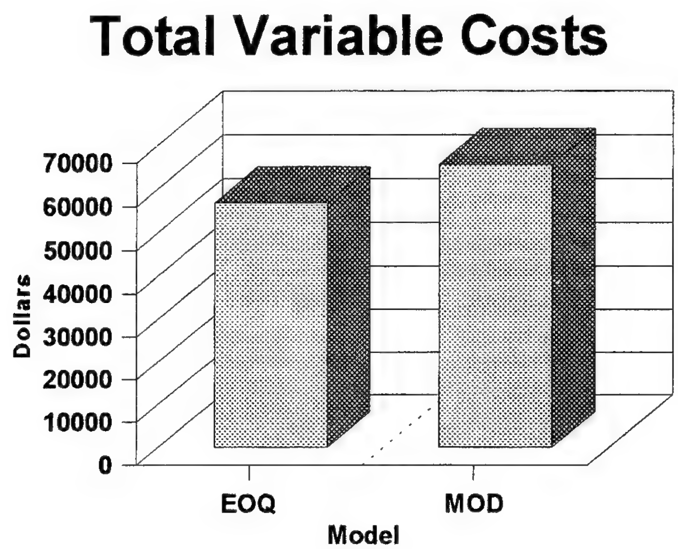

Figure F.7. Scenario #3 TVC Comparison

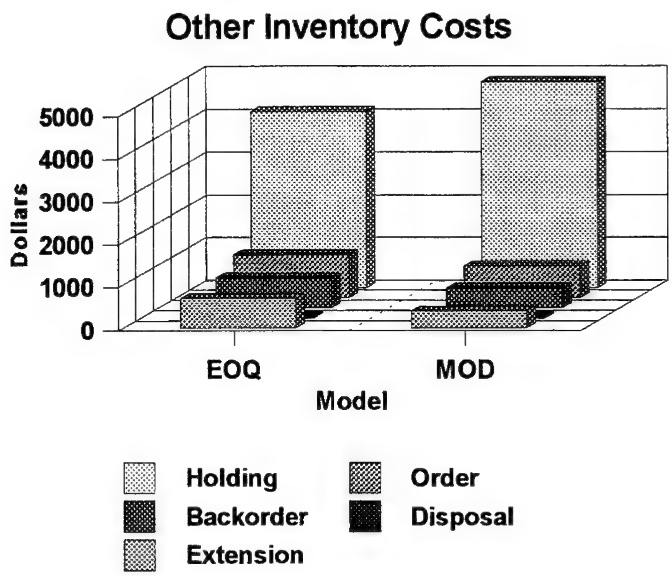

Figure F.8. Scenario #3 Costs Comparison

5. **Scenario #4 simulation results (percentage of material that fails test for extension increased from 20% to 40%)**

Costs/Model	EOQ	MOD
TVC	$64,116	$61,847
Purchase	$58,080	$55,460
Order	$1,219	$689
Holding	$3,957	$4,325
Backorder	$729	$588
Disposal	$95	$105
Extension	$94	$681

Table F.6 Scenario #4 Models' Costs Summaries.

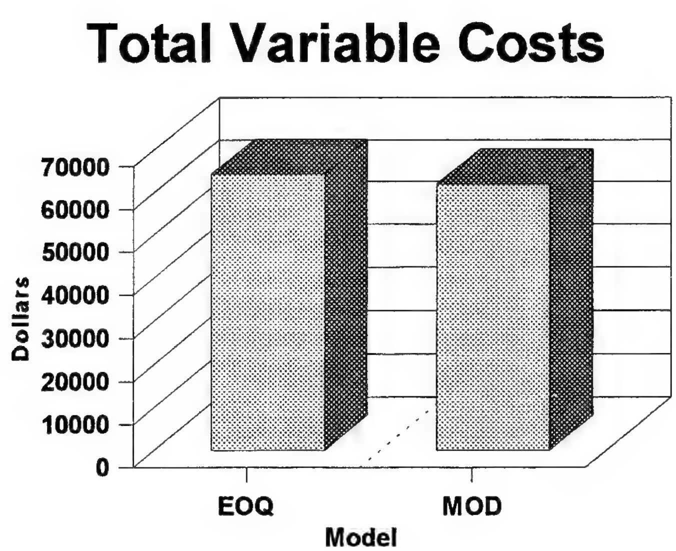

Figure F.9. Scenario #4 TVC Comparison

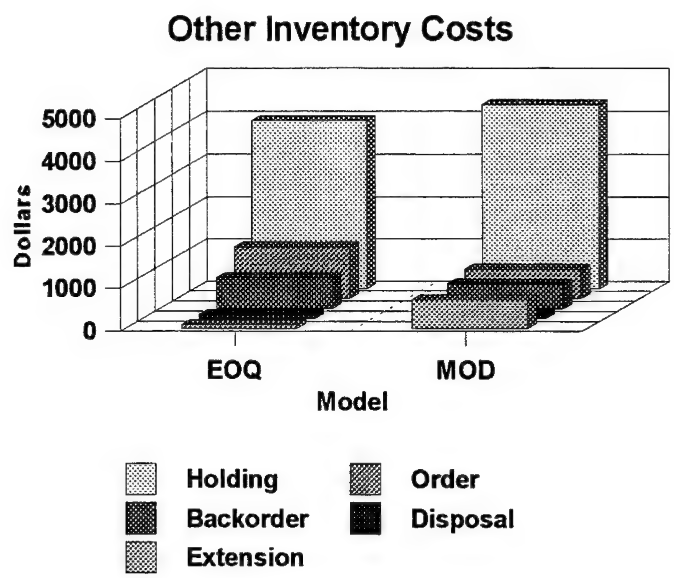

Figure F.10. Scenario #4 Costs Comparison

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